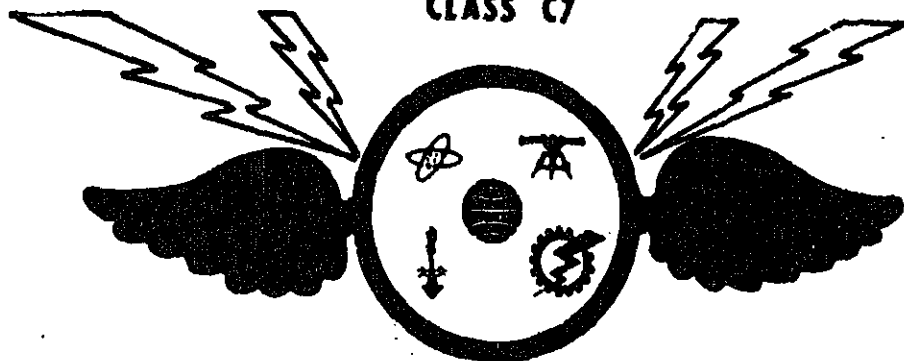


**FOR  
AVIONICS INTERMEDIATE COURSE**

**CLASS C7**



**UNIT XI**

**CNTT-M1558**

**PREPARED BY**

**NAVAL AIR TECHNICAL TRAINING CENTER  
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MILLINGTON, TENNESSEE**

**PREPARED FOR**

**NAVAL TECHNICAL TRAINING COMMAND**

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11-2-1A	ASSIGNMENT SHEET
11-2-1S	STUDENT ACTIVITY GUIDE
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11-10-1I	INFORMATION SHEET

# Principles of Radar

**INTRODUCTION:** The purpose of this assignment is to familiarize the student with the basic fundamentals of pulse radar systems. A thorough knowledge of the basics involved in radar range determination is necessary for the technician to effectively test and evaluate the more complex systems.

Along with the knowledge of radar range determination principles the technician must be familiar with the associated terminology and its relationship to system characteristics.

## LESSON TOPIC LEARNING OBJECTIVES:

- 1.1.1 Given statements concerning the factors that affect maximum free space range of a radar as stated in the Basic Radar Equation, select the correct statement(s).
- 1.1.2 Given a formula sheet and the values of pulse width and pulse repetition frequency solve for the values of minimum range and maximum unambiguous range.
- 1.1.3 Given specified radar characteristics, solve for the pulse width.
- 1.1.4 Given specified radar characteristics, solve for pulse repetition frequency.
- 1.1.5 Given specified radar characteristics, solve for average power.
- 1.1.6 Given statements concerning the factors that affect the ability of a radar receiver to detect the presence of an echo pulse, select the limiting factor(s).
- 1.1.8 Given statements concerning the controlling factors of azimuth resolution, select the correct statements(s).

Read, Reintjes and Coate Principles of Radar,  
Edition, McGraw-Hill, 1952 Chapter 1, p  
thru 53.

Skolnik, M. L, Introduction to Radar Sy  
McGraw-Hill, 1962, Chapter One and Two,  
to pp 70

COMPLETE: STUDENT ACTIVITY GUIDE 11.1.1S

STUDY QUESTIONS:

1. Define the term Radar, and the principle by which it is able to measure the distance.
2. Solve for the time required for a radar's transmitted wave to travel to an object, a distance of 9800 meters from the radar, and return.

\_\_\_\_\_ is the major assembly of the radar system which establishes the center spectral frequency of operation for the radar.

\_\_\_\_\_ is the major assembly of the radar system which establishes the time base for accurate range measurement.

\_\_\_\_\_ is the major assembly of the radar system which establishes the pulse repetition frequency (PRF).

Solve for the pulse repetition frequency (PRF) for a radar system operating with a duty cycle (DC) of .00013 and a pulse width (PW) of 4.5 microsecond.

The range resolution of a radar system is:

- a) Improved by decreasing the pulse repetition frequency (PRF).
- b) Limited by the antenna beamwidth on shortrange operation.
- c) Limited by the pulse duration on longrange operation.
- d) Limited by the pulse duration at all times.

With a 2.5 microsecond pulse duration, an object extending 16 meters in length to the radar will create an indicator echo pip covering.

- a) 750 meters on the range scale.
- b) 40 meters on the range scale.
- c) 375 meters on the range scale.
- d) 2460 meters on the range scale.

Solve for the pulse width (PW) of a radar system operating on the 150km range with a duty cycle of .001 and a pulse repetition frequency (PRF) of 1000Hz.

\_\_\_\_\_ microseconds

A radar system is operating with a transmit time of 4.5 microseconds. Solve for the distance that must

- i. With reference to question h, solve for the minimum detection range.

\_\_\_\_\_ meters

- j. Solve for the maximum unambiguous range of a radar system operating on a high PRF of 1420Hz

\_\_\_\_\_ meters

- k. "Second time around echoes" are best reduced by:

- a) Varying the pulse repetition frequency.
- b) Increasing the pulse width.
- c) Decreasing receiver sensitivity.
- d) Decreasing the pulse width.

- l. Solve for the peak power ( $P_{pk}$ ) of a radar system having a maximum duty cycle (DC) of .00014 and an average power ( $P_{ave}$ ) of 630 watts

\_\_\_\_\_ watts

- m. In order to double the free-space maximum range of a radar system the peak transmitter power must be

- a) Doubled
- b) Increased by a factor of four.
- c) Increased by a factor of sixteen.
- d) Decreased by a factor of four.

- n. \_\_\_\_\_ is the primary limiting factor in a radar receiver's ability to detect weak echo returns.

- o. A radar system with a conical beam pattern of 1.5 is scanning a small target aircraft at 11km. The radars system's scan rate is 250 rpm. Solve for the width of the target aircraft as it would appear on the radar's indicator.

\_\_\_\_\_ meters



of Radar Modulators and the different methods of charging a PFN. Review the listed learning objectives, then test yourself with the study questions provided.

#### LESSON TOPIC LEARNING OBJECTIVES:

- 11.2.1 Given the five characteristics of a Radar Modulator Pulse and a list of their effect on Radar performance, correctly match the characteristic to its effect on Radar performance.
- 11.2.2 Given statements concerning d-c resistance method of charging of a pulse forming network (PFN), select the correct statement(s).
- 11.2.3 Given statements concerning d-c resonant method of charging of a PFN without a charging diode, select the correct statement(s).
- 11.2.4 Given statements concerning d-c resonant method of charging of a PFN using a diode, select the correct statement(s).
- 11.2.5 Given statements concerning the function of and reason for the inverse diode in a Line Pulsing Modulator, select the correct statement(s).
- 11.2.6 Given statements concerning the function of and theory of operation of the Thyatron in a modulator, select the correct statement(s).
- 11.2.7 Given statements concerning the function of the Pulse Transformer in a Radar Modulator, select the correct statement(s).
- 11.2.8 Given a schematic diagram of a typical Line Pulsing Modulator with appropriate values, solve for  $R_m$ .
- 11.2.9 Given a schematic diagram of a typical Line Pulsing Modulator with appropriate values, solve for PR.



11. Given a schematic diagram of a typical Line Pulsing Modulator with appropriate values, solve for  $Z_o$ .

#### HOMEWORK ASSIGNMENT:

1. Read NAVPERS 10318-D Aviation Electronics Technician 1 & C, pp 256-268
2. Study notes taken in class.

COMPLETE: STUDENT ACTIVITY GUIDE 11.2.1S

#### HOMEWORK QUESTIONS:

1. Name the three common methods of controlling the discharge time of PFN's.
2. What are the advantages/disadvantages of d-c resistance charging of a PFN? Of d-c resonant charging?
3. Why are Bifilar windings commonly used in the Pulse Transformer?
4. What is frequency pulling?
5. What is frequency pushing?

- a. it is impossible to measure the delay in an actual line
  - b. an actual line would be too long for most applications
  - c. Actual lines are too costly
  - d. actual lines are inefficient
2. Charging a PFN utilizing a charging diode and an a-c source, the efficiency is approximately:
- a. 25% less than d-c Resistance charging
  - b. 20% more than d-c Resonance charging
  - c. 25% greater than a-c Resonant charging
  - d. 20% greater than d-c Resistance charging
3. The duration of the Modulator's pulse depends upon:
- a. the applied voltage
  - b. the values of inductance and capacitance in each LC section
  - c. the values of inductance and capacitance in each LC section and the number of LC sections
  - d. the deionization time of the Thyatron
4. Addition of charging diode to the resonant charging circuit permits the storage element to charge to:
- a. a d-c voltage twice the applied d-c voltage
  - b. 95% of the applied d-c voltage
  - c. 180% of the applied d-c voltage
  - d. the value of the applied voltage and to remain constant until discharged
5. A Pulse Forming Network's switching device must have which of the following characteristics?
- a. close and open within microseconds
  - b. conduct large currents and withstand large voltage
  - c. consume only a fraction of the power that passes within it
  - d. All of the above

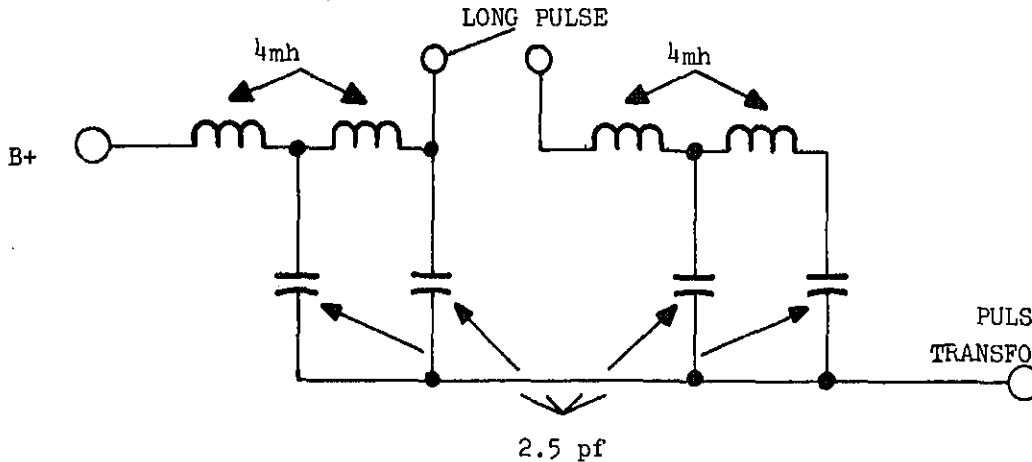
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Figure 2



- 6 . Calculate the Pulse Width of the Pulse Forming Network shown in figure 2.
  - a. 0.1  $\mu\text{sec}$
  - b. 0.2  $\mu\text{sec}$
  - c. 0.4  $\mu\text{sec}$
  - d. 0.8  $\mu\text{sec}$
- 7 . Using the Values shown in figure 2 with the long pulse switch engaged, calculate the Pulse Width of the Pulse Forming Network with the Long Pulse switch engaged.
  - a. 0.4  $\mu\text{sec}$
  - b. 0.6  $\mu\text{sec}$
  - c. 0.7  $\mu\text{sec}$
  - d. 0.8  $\mu\text{sec}$

- 11.3.2 Given statements concerning the location of the TR-tubes and their respective junctions within the rad waveguide assembly, select the correct statement(s).
- 11.3.3 Given statements concerning balanced duplexer operation select the correct statement(s).
- 11.3.4 Given a schematic representation and statements concerning the operation of a ferrite duplexer select the correct statement(s) that describe(s) the direction and the amount of phase shift offered to a signal by various paths through the device.
- 11.3.5 Given statements concerning the purpose of SHUTTERS select the correct statement(s).

STUDY ASSIGNMENT:

Read: Information Sheet 11.3.1I Duplexers

Complete: Student Activity Guide 11.3.1S

STUDY QUESTIONS: Refer to Student Activity Guide

State the advantages of the Ferrite Duplexer.

What is the purpose of the shutter.

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## A. Duplexers

The duplexer is the device that (1) switches the antenna to either the transmitter or the receiver and serves to protect the receiver from burnout or damage during transmission. Duplexers are generally gas-discharge tubes but ferrites and solid-state varactor diodes have also been used. Several forms of passive duplexers using the principle of hybrid junctions or polarization rotation were discussed in Sec. 3.2. In this section, active duplexers using solid-state switching element are discussed. In a typical application, transmitter power might be 10 watts and the maximum signal at the receiver might be a few watts. Therefore the duplexer must provide, in this instance, on the order of 60-dB isolation between transmitter and receiver, with only negligible loss in the transmitted power.

**Branch-type Duplexers.** The principle of the branch-type duplexer is illustrated in Figure 1. It consists of a transmit-receive (TR) switch and an anti-transmit-receive (ATR) switch, both of which are gas-discharge tubes. When the transmitter is turned on, the TR and the ATR tubes ionize; they break down, or fire. The TR in the fired condition acts as a short circuit to prevent transmitter power from reaching the receiver. Since the TR tube is located a quarter wavelength from the main transmission line, it appears as a short circuit at the receiver but as an open circuit at the transmitter and does not impede the flow of transmitter power. The function of the TR, therefore, is to disconnect the receiver from the transmitter during transmission and to protect the receiver from excess power.

The ATR breaks down on transmission along with the TR. Since it is displaced a quarter wavelength from the main transmission line, the short circuit produced by the ATR in the fired condition appears as an open circuit on the transmission line. Thus the ATR has no effect on transmission.

During reception the transmitter is turned off; neither the TR nor the ATR is fired. The open circuit of the ATR is located a quarter wave from the transmission line and appears as a short circuit across the line. If the apparent short circuit is located a quarter wave from the receiver end of the line, the transmitter is effectively disconnected from the receiver and the echo signal power is directed toward the receiver.

spark gap is well suited as a TX switch since its impedance is low in the unfired condition and low when fired. It is not satisfactory, however, from a practical point of view. Its characteristics change with use; it must be adjusted at frequent intervals; and its life is limited.

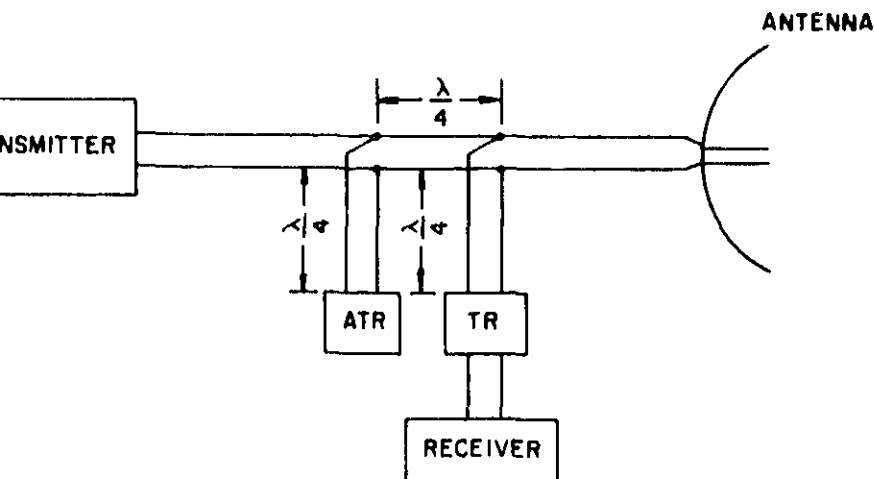


FIGURE 1. Principles of branch-type radar duplexer. The TR provides receiver protection and switching; the ATR channels echo power into the receiver.

The performance of the simple spark-gap TR can be improved by enclosing it in a partially evacuated glass envelope operated in a properly designed cavity. By enclosing the spark gap in a glass (or other suitable material) envelope, at a gas pressure of a few millimeters of mercury, both the breakdown voltage and the operating voltage are reduced.

The gas filling used in the TR tube must ionize and deionize quickly and easily. It is in trying to meet these requirements that the TR tube designer sometimes encounters difficulty. In order to obtain a short deionization time, the electrons formed in the discharge must be removed quickly once the RF power is turned off. Although electrons may be removed by direct recombination with the positive ions to form neutral atoms, this process is not too favorable and long recovery times are the result. If the recovery is to be rapid, some third body must be present, such as a neutral atom or the walls of the discharge, to act as a catalyst. One method of speeding recovery is to employ a gas with a high affinity for electrons; for example,

argon and water vapor have also been used. A TR tube filled with a pure noble gas like argon has low breakdown voltage and offers good receiver protection and relatively long life. However, conventional TR tubes filled with pure noble gases have relatively long deionization times (on the order of milliseconds) and are not suitable, except for long-range radar applications (satellite or ballistic-missile detection), where it is not necessary to detect targets at short ranges.

Recombination times may be improved by the presence of the tube walls or other surfaces. In some tubes quartz wool is located in the discharge region for this purpose. It consists of very fine fibers and has a large surface-to-volume ratio. Quartz wool is especially useful in tubes filled with the pure noble gases. Surface recombination permits a recovery time in argon on the order of 50  $\mu$ sec. Even shorter recovery times have been reported with argon TR tubes especially designed to improve recovery by surface recombination. The arc loss in argon-filled tubes is exceptionally low compared with the loss in water-vapor-filled tubes.

The TR is not a perfect switch; some transmitter power always leaks through to the receiver. The envelope of the RF leakage pulse might be similar to that shown in Figure 2. A

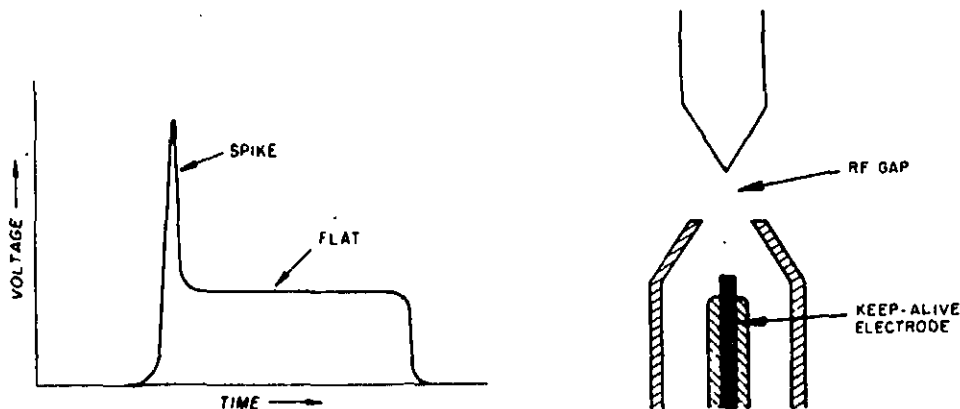


FIGURE 2 Example of leakage pulse through a TR tube.

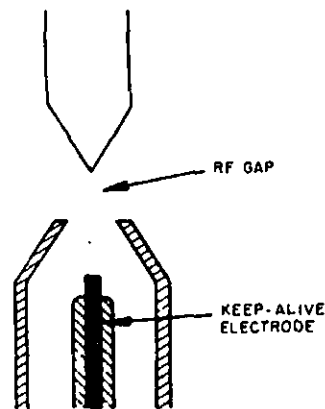


FIGURE 3 TR tube electrode showing arrangement of the keep-alive.

To ensure reliable and rapid breakdown of the TR tube upon application of the RF pulse, an auxiliary source of electrons is often supplied to the tube. An electron source can be obtained with a weak "keep-alive" d-c discharge between an additional electrode introduced into the tube and one of the electrodes of the TR (Fig. 3). Electrons from the keep-alive discharge diffuse into the TR gap, where they act to trigger the breakdown once RF power is applied.

The keep-alive generates noise just as does any other gas-discharge device. If too strong a discharge is maintained the noise level might be high enough to degrade the receiver sensitivity.

An example of a typical TR tube is shown in Figure. 4. It consists of a length of waveguide sealed at both ends with glass or ceramic windows transparent to microwave frequencies. Two TR gaps formed by the truncated cones, spaced a quarter of a guide wavelength apart, provide greater bandwidth than possible with a single TR gap. The truncated cones and the baffles form a resonant-filter section. The cones are the capacitive elements and the baffles are the inductive elements. The prime function of the filter section is to aid the breakdown process by producing a relatively high value of electric field strength in the region of truncated cones. Not only does the use of two TR gaps lead to greater bandwidth than is possible with a single gap, but the amount of power which leaks through during the flat portion of the pulse is less since both gaps are fired and contribute to the attenuation. Each of the two windows is matched with an inductive iris. They are of lower Q than the TR gaps and, being spaced a quarter wavelength from each of the TR gaps, act to further increase the bandwidth. The keep-alive discharge is placed in the gap farthest from the transmitter. In operation, the gap with the keep-alive discharge breaks down first, followed by the breakdown of the remaining gap and the breakdown at the input window nearest the transmitter. The main discharge takes place at the input window.

The attenuation during the gap is determined by the discharge at the input and at each of the two gaps. The combined attenuation can be on the order of 80 to 100 db. Leakage energy in the initial spike is determined by the design of the keep-alive gap and by the nature and pressure of the gas fill. Arc loss depends primarily upon the characteristics of the input window.

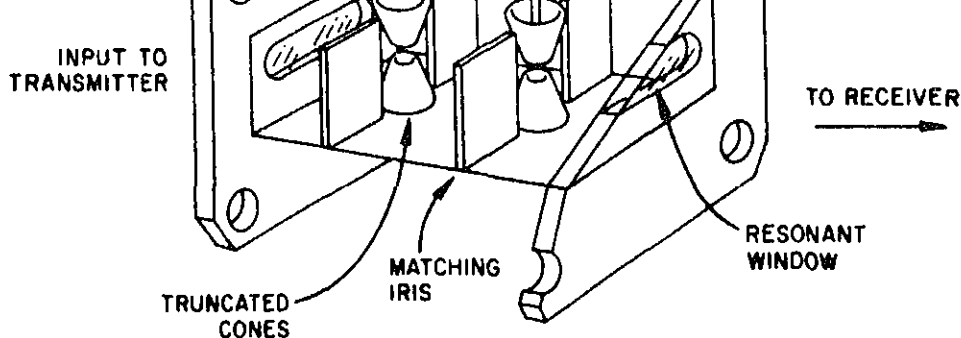


FIGURE 4 Example of a typical TR tube.

The gas-fill pressure for minimum loss and recovery time is contrary to that required for minimum spike and flat leakage. These functions can be separated by using a gas-filled glass capsule sealed to the input window which provides a separate and distinct gas fill for the input window.

One of the factors limiting the life of TR tubes is the disappearance, or "clean-up," of the gas filling. Clean-up is the gradual decrease of pressure caused by the chemical combination of the gas with the electrodes and by the gas molecules becoming imbedded in the gap electrodes. Gas clean-up means that as the ages, it no longer operates at the pressure for which it was designed. Longer recovery times result, causing echo signals from nearby targets to be lost. This may be an important consideration in short-range radar. Sputtering of the material from the electrodes is also a common occurrence in TR tubes, especially those with keep-alive electrodes. Sputtering causes short circuiting of the keep-alive and detuning of the resonant circuit. The end of life of a TR tube is determined more by the amount of leakage power which it allows to pass than by physical destruction or wear. A TR tube is considered unsatisfactory when it no longer affords receive protection. Several hundred hours of life is considered typical of conventional TR tubes.

Both the keep-alive and the water-vapor filling in TR tubes reduce the useful life. If rapid TR breakdown and rapid recovery times were not necessary, simple and reliable TR tubes of long life could be constructed using pure noble gases.

the arc loss can be sufficient to melt the input window. The arc loss in tubes filled with argon may be 0.1 db or less. On reception, the TR tube introduces an insertion loss of about 1 to 1 db, which attenuates the echo signal. The arc loss, insertion loss, and the keep-alive noise reduce the sensitivity of the radar and should be taken into account in any accurate prediction of radar performance.

The ATR tube has less stringent demands placed upon it than does the TR tube. Therefore it is usually simpler. An ATR might use a pure noble gas such as argon since recovery time generally is not of importance. Furthermore, priming agents such as the keep-alive are not needed. The absence of both chemically active gases and a keep-alive results in ATR tubes having longer lives than TR tubes.

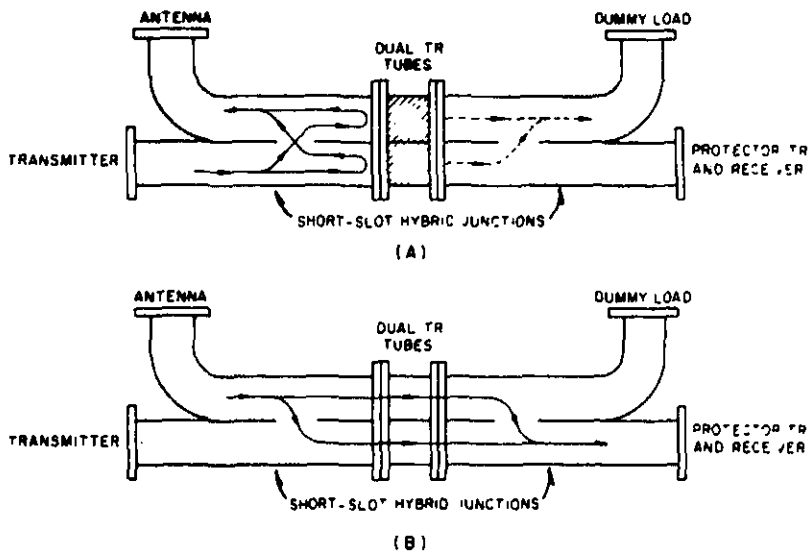


FIGURE 5 Balanced duplexer using dual TR tubes and two short-slot hybrid junctions. (a) Transmit condition; (b) receive condition.

### Balanced Duplexer.

There are several circuit arrangements of TR and ATR tube for switching and for receiver protection in addition to the branched duplexer. The branched duplexer is the simplest configuration, but is non-inherently broadband. A more broadband arrangement is the balanced duplexer (Fig. 6). In principle, its bandwidth is limited only by that of the waveguide. Balanced duplexers employ a hybrid junction of some sort. (A hybrid junction is a four-terminal network of waveguide, coax, or other

antenna arm as shown. The short-slot hybrid has the property that each time the energy passes through the slot in one direction, its phase is advanced  $90^\circ$ . Therefore the energy must travel as indicated by the solid lines. Any energy that leaks through the TR tubes (shown by the dashed lines) is directed to the arm with the matched dummy load and not to the receiver. In addition to the attenuation provided by the TR tubes, the hybrid junctions provide an additional 20 dB of isolation.

On reception the TR tubes are unfired and the echo signals pass through the duplexer and into the receiver as shown in Figure 5b. The power splits equally at the first junction because of the  $90^\circ$  phase advance introduced on passing through the slot, the energy recombines in the receiving arm and the dummy-load arm.

An example of a balanced duplexer is shown in Figure 6. This particular X-band unit operates over the frequency range from 8,490 to 9,578 Mc and is capable of withstanding 100 W peak power. The insertion loss on reception (duplexer loss) is 1.2 db.

A low-power TR tube (which might also be a diode) known as a receiver protector, is often placed between the balanced duplexer and the receiver to safeguard the receiver against

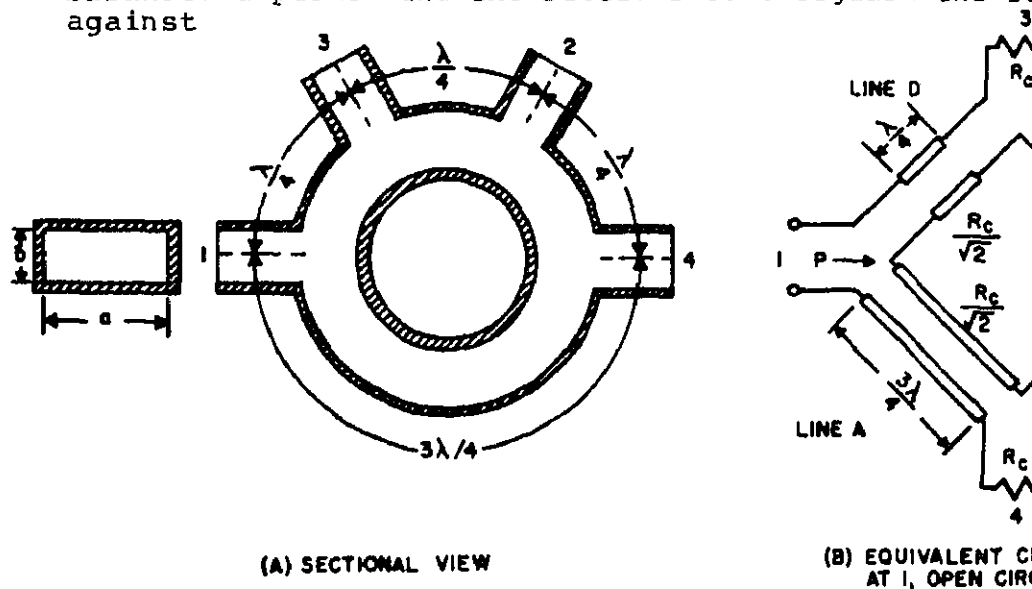


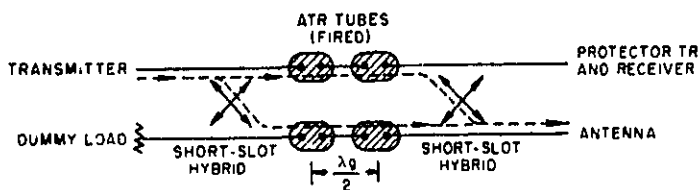
FIGURE 6 Waveguide hybrid junction of one and one half-wave type



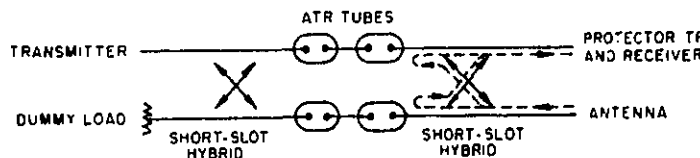
may be designed to fire at low power levels and to provide the optimum receiver protection. In this manner each tube is designed to perform its single function in an optimum manner instead of compromising the design by combining the two functions of switching and protection in a single tube.

Another form of balanced duplexer uses four ATR tubes and two hybrid junctions (Fig. 7). The ATR tubes reflect the echo signal into the receiver in this duplexer arrangement as contrasted with the balanced duplexer of Figure 5, where the TR tubes reflected the transmitter power into the antenna. During transmission (Figure 7a), the ATR tubes fire and high power is allowed to pass to the antenna. Dashed lines show the flow of power. During reception (Figure 7b), the ATR tubes present a high impedance, which results in the echo signal power being reflected to the receiver. A protector TR tube ahead of the receiver prevents excess signal power from entering the receiver. The ATR type of balanced duplexer has high power-handling capacity that that in Figure 5, but it has less bandwidth.

Duplexer action may also be obtained with two hybrid junctions and a half-wavelength power-sensitive phase shifter, as shown in Figure 8. The power from the transmitter is applied to arm 1, where it divides equally between arms 3 and 4. If the path lengths between the two hybrids are equal, all the power will pass into the antenna arm 7 because of the  $90^\circ$  phase shifts introduced by the hybrid junctions. On reception, the

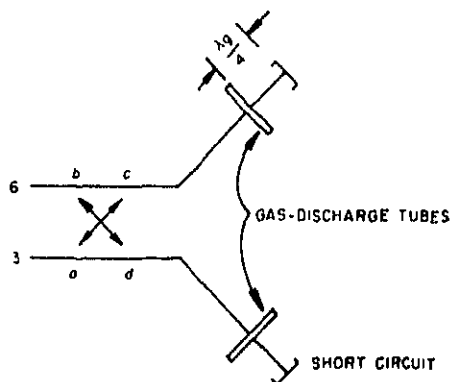


(A)



(B)

FIGURE 7 Balanced duplexer using ATR tubes. (a) Transmit condition



(B)

FIGURE 8 (a) Principle of the phase-shift duplexer; (b) half-wavelength, power-sensitive phase shifter.

phase shift in the power-sensitive phase shifter between arms 3 and 6 is increased by half a wavelength. The phase shift of the low-power signal will cause it to enter the receiver arm rather than the transmitter arm.

A method of providing a half-wavelength power-sensitive phase shifter is shown in Figure 8b. It consists of a hybrid junction and two gas-discharge tubes. Metal plates are spaced a quarter wavelength behind the tubes. When a high-power transmitter pulse (from arm 3) enters arm 3, it is divided equally between arms c and d. The gas-discharge tubes break down, and the power is reflected and appears to be delivered to arm 6 of Figure 8a). On reception, the echo signal enters arm b. The echo power is too weak to break down the gas-discharge tubes; consequently, the low-power signal travels a quarter wave farther before being reflected to the metal short. Thus the received signal travels a total of a wavelength more than the high-power transmitter pulse. It has been claimed that the power-handling capacity of the phase-shift duplexer is twice that of a balanced duplexer using the same components.

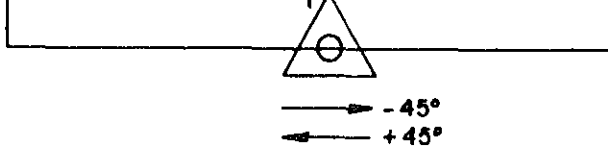


FIGURE 9 Nonreciprocal differential phase-shift ferrite duplexer.

## Ferrite Duplexers

There are a number of methods by which ferrite devices such as faraday rotators, isolators, circulators, and phase shifters may be used in duplexer applications. The phase-shift duplexer described in Figure 8 may be used with a ferrite phase shifter as well as with a gas-discharge device. The nonreciprocal differential phase-shift ferrite duplexer is shown in Figure 9. The transmitter power enters the H-plane arm of a magic T and splits equally into the two collinear arms. In one arm the phase is advanced  $45^\circ$  by the ferrite phase shifter, and in the other, it is retarded  $45^\circ$ . The two signals then enter a short-slot hybrid junction, and because the phase relationships are proper, they recombine in the antenna arm.

On reception, the signal power is divided equally by the short-slot hybrid junction. The phase shifts introduced by the ferrites are now reversed because propagation in the nonreciprocal phase shifter is in the opposite direction; that is, the phase of the upper arm is retarded  $45^\circ$ , and in the lower arm it is advanced  $45^\circ$ . This phase differential plus the  $90^\circ$  phase advance introduced in the lower arm by the short-slot hybrid results in a total phase difference of  $180^\circ$  between the signals in the two arms. This is the proper phase relationship if the two signals entering the collinear arms of the magic T are to recombine in the E-plane (receiver) arm with no energy entering the H-plane (transmitter) arm. A protector TR may be inserted in the receiver arm as protection against transmitter leakage, reflected power from the antenna during transmission, and radiation from nearby radars during the receiving period.

Ferrite duplexers have the advantage of shorter recovery times and longer life than gas-discharge duplexers. They are relatively broadband. However, they are usually of larger size and weight and require magnetic fields for their operation. Another form of all solid-state duplexer consists of a three-port ferrite circular with a diode limiter ahead of the receiver.

"shutter tube" in which one or more cones are short  
solenoid-activated device.

LESSON TOPIC LEARNING OBJECTIVES:

- 11.4.1 Given a list of statements concerning the shape and characteristics of a parabolic-reflector, select the correct statement(s).
- 11.4.2 Given a list of statements concerning the shape and characteristics of a cosecant-squared reflector, select the correct statement(s).
- 11.4.3 Given a list of statements concerning the reasons for a cosecant-squared reflector, select the correct statement(s).
- 11.4.4 Given a list of definitions, select the correct definition for antenna reciprocity.
- 11.4.5 Given a list of definitions, select the correct definition for an isotropic antenna.
- 11.4.6 Given a list of definitions, select the correct definition for directive gain.
- 11.4.7 Given a list of definitions, select the correct definition for power gain.
- 11.4.8 Given a list of statements concerning the electrical characteristics of an array antenna select the correct statement(s).
- 11.4.9 Given a list of statements, select the correct statements which describe the beam characteristics that determine
  - a. bearing/azimuth resolution.
  - b. altitude resolution.
- 11.4.10 From a table of statements, match the statements given with lobe configurations with their applications.

- 11.4.15 Given a list of statements, match the two types of radome construction to their comparative advantages.

#### STUDY ASSIGNMENT

Read:

1. Skolnik, M.L. Introduction to Radar Systems, McGraw-Hill, 1962, Ch 7, pp. 223-250, Ch 8, pp 278-318.
2. Reintjes and Coate, Principles of Radar, McGraw-Hill, Ch 13, pp. 937-958.

COMPLETE: Student Activity Guide 11.4.1S

STUDY QUESTIONS: None

What is an isotropic antenna?

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When can directive gain equal power gain?

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The effective aperture of a radar antenna is described as a measure of?

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What geometric contour is the most widely used in the construction of radar antenna reflectors?

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What is the reason for using a parabolic reflector?

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List the three factors whose product determines the overall efficiency of a radar antenna.

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What two main factors determine the gain of a parabolic reflector?

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---

squared pattern.

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11. What is the effect on antenna gain when a paraboloid is changed to operate as a cosecant-squared reflector?  

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12. List two methods of generating an asymmetrical (fan) pattern from a parabolic reflector.  

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---
13. Describe the geometrical configuration of a linear antenna.  

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14. Describe the geometrical configuration of a planar antenna.  

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15. What type of antenna pattern will a linear array present when the phase relationships of the individual elements are such that it causes the primary pattern to be perpendicular to the array?  

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18. In what plane is the flare of the feed horn made to feed the truncated paraboloid?

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19. What are the three basic feed methods of parasitic phased arrays?

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20. What are the two types of radome construction?

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2.  
The requirements of the antenna and its feed system are basically the same for a radar as for communication systems, although they may appear quite different, due mainly to the frequencies used in radar. The purpose for which the antenna is to be used will also determine the design of the array. For instance, a fire-control system requires that the energy be radiated in a very narrow pattern, whereas other radars may require a wide beam, at least in one of its dimensions.

Another consideration in radar antenna design is the fact that the antenna must be used for reception of the echo signal shortly after the transmitter has fired.

The same antenna is used for both transmit and receive functions.

#### REFERENCES:

1. SKOLNICK, M.L. Introduction to Radar Systems, McGraw-Hill 1958, Ch 7, pp. 223-250, Ch 8, pp. 278-318.
2. REINTJES and COATE, Principles of Radar, McGraw-Hill 1952, Ch 13, pp. 937-958.

#### ADDITIONAL INFORMATION

#### RADAR ANTENNA SYSTEMS

##### 1. Types of Antennas

1. Parabolic Reflectors - Virtually all airborne antenna systems use a paraboloidal surface as a reflector to shape the radiation beam. The full-parabola type will create a beam that is conical or pencil-shaped, and the parabola may be modified in one or more of its dimensions to achieve the desired radiation pattern.

- a. Figure 1 illustrates the usefulness of a parabolic surface as a reflector. If a beam of parallel waves is incident upon the curved surface, the rays will be reflected and made to cross at a point called the focus.

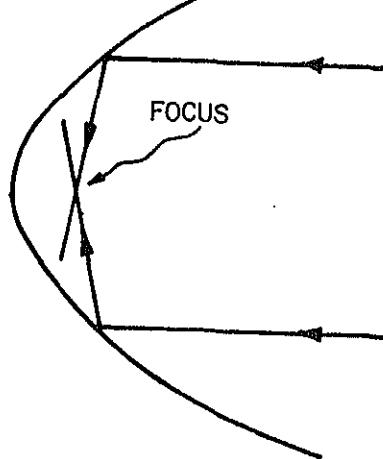


Figure 1

- c. The feedhorn of the antenna system is normally placed slightly outside the focal point, in order to aid in the sharpening of the radiated pattern. The feedhorn will be designed and placed in such a manner that it will illuminate the entire reflector, yet not cause a great amount of energy to miss the dish entirely and create back-lobes (called Spillover).

## 2. Orange peel reflectors (Figure 2)



Figure 2

- c. The feedhorn for this type system would also be specially shaped, since the dish must be illuminated before. The end of the waveguide is flared to cover the radiated beamwidth of the feedhorn, with the flare producing a narrower beam. Therefore, the narrower dimension of the feedhorn will illuminate the long dimension of the reflector, and create the narrow dimension of the radiated beam pattern.

### 3. Cosecant Squared Reflectors (Figure 3)

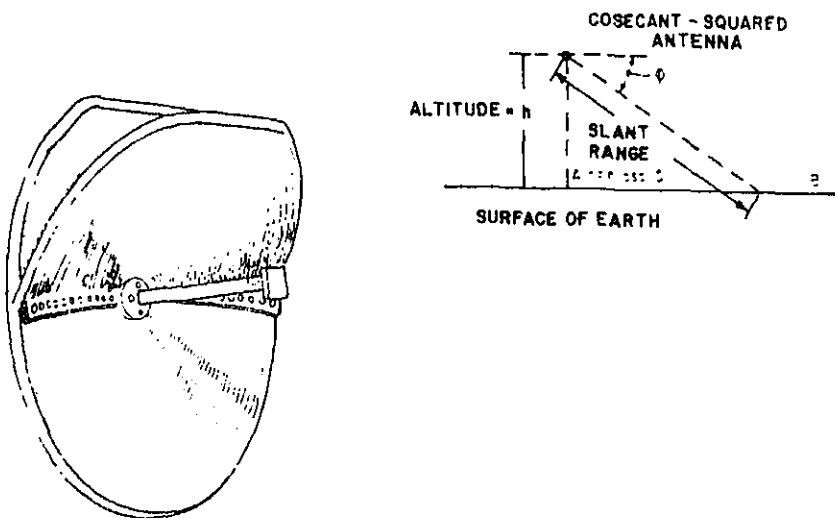
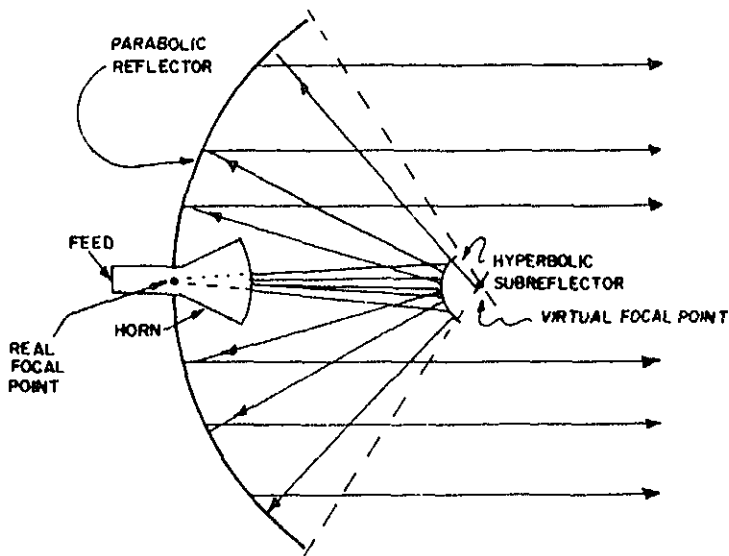


Figure 3

- a. The upper portion of the parabola is bent forward to cause part of the energy to be radiated downward, and additional energy to be added to the beam for distant targets. The field intensity is such that it will vary as the square of the cosecant of the angle between a horizontal line projecting from the antenna and

#### 4. Cassegrain Antenna (Figure 4)



- a. The principles of the Cassegrain Antenna is that it uses two reflector surfaces. The larger (primary) reflector has a parabolic contour while the smaller (secondary) subreflector has a hyperbolic contour.
- b. Two focus points are produced. The real focal point produced by the contour of the hyperbolic subreflector is normally located at the vertex of the parabola. The real focal point is where the feed system will be located. The virtual focal point produced by the contour of the parabolic reflector is located beyond the subreflector.
- c. Parallel rays of energy reflected from a target are collected and reflected by the parabolic surface as a convergent beam to the hyperbolic surface where they are re-reflected to the real focal point and transferred to the waveguide via the feed system.

#### B. System Requirements

these requirements.

- b. The beamwidth is held to a narrow pattern in plane, so that azimuth information accuracy and bearing resolution is not impaired.

## 2. Height Finding Radars

- a. A fan beam is required for height finding operations as well as in a search radar, except that altitude resolution must be maintained. A vertically scanned fan beam is satisfactory for this purpose.
- b. The antenna is rotated in azimuth as a search radar until a target is detected. At this time, the rotation is stopped, and the beam is "nodded" vertically to determine the angle to the target.

## 3. Fire Control Radars

- a. Requires a fan beam for search mode, and a narrow beam for accurate tracking of targets.
- b. One method of accomplishing both features with one antenna is to apply a spoiler to a parabola, which can be moved out of the way when performing search operations.
- e. Another method is by off-setting the feedhorn to half the beamwidth and rotating the feedhorn during the Track mode.

# TOPIC LEARNING OBJECTIVES:

- 1 Given a block diagram of a typical radar receiver and a list of functions, MATCH the function to the appropriate block.
- 2 Given statements concerning the function and operation of the local oscillator, SELECT the correct statement(s).
- 3 Given statements concerning the function and operation of the mixer, SELECT the correct statement(s).
- 4 Given statements concerning radar I-F amplifier design considerations, SELECT the correct statement(s).
- 5 Given statements concerning video amplifier design considerations, SELECT the correct statement(s).
- 6 Given statements concerning the function and operation of IAGC circuits, SELECT the correct statement(s).
- 7 Given statements concerning the function and operation of FTC circuits, SELECT the correct statement(s).
- 8 Given statements concerning the function and operation of STC circuits, SELECT the correct statement(s).
- 9 Given statements concerning the function and operation of a synchronizer in a radar, SELECT the correct statement(s).

## ASSIGNMENT:

- Read: 1. Aviation Electronics Technician 1 and C, NAVPERS 10318-D, pp. 198-208.
2. Information Sheet No. 11.5.1I "Radar Receivers."
3. Information Sheet No. 11.5.2I "Synchronizers."

NOTE: STUDENT ACTIVITY GUIDE 11.5.1S

QUESTIONS: NONE

- ☐ a. accuracy of the afc system.
  - ☐ b. sensitivity of the receiver.
  - ☐ c. value of the intermediate frequency.
  - ☐ d. signal to noise ratio of the receiver.
2. The minimum usable signal in a radar set is
- ☐ a. ineffective below one milliwatt.
  - ☐ b. the minimum signal echo that will actuate the afc system.
  - ☐ c. the signal strength that barely exceeds a signal-to-noise ratio of 1/1.
  - ☐ d. the signal strength that barely saturates the final i-f amp.
3. The mixer in a radar set mixes the
- ☐ a. video and audio portions of the echo.
  - ☐ b. returning radar energy with the local oscillator energy.
  - ☐ c. intermediate-frequency energy with the local oscillator energy.
  - ☐ d. crystals in the input of the i-f amplifier.
4. The purpose of the Wallman cascode amplifier is to provide
- ☐ a. wide bandpass, with the gain characteristic of a pentode and the noise characteristic of a diode.
  - ☐ b. narrow bandpass, high gain, and low noise at the input of the i-f amplifier.
  - ☐ c. a reference level to determine the signal-to-noise level.
  - ☐ d. isolation between the input crystals and the i-f stage.
5. The primary function of the afc system is to
- ☐ a. keep the klystron's frequency constant despite variations of transmitter variations.
  - ☐ b. keep the intermediate frequency constant despite transmitter's variations.
  - ☐ c. keep the transmitter frequency constant despite load variations.
  - ☐ d. keep the transmitter's frequency constant despite variations of the load.



the frequency.

d. zero.

The basic function of the timer in a radar system is to

- a. fire the transmitter and start the sweep circuits at the proper time.
- b. start the range marker circuits.
- c. synchronize the blanking and gating circuits.
- d. provide a variable PRT for different ranges.

A radar timer is sometimes referred to as a

- a. stabilizer.
- b. range mark generatro.
- c. synchronizer.
- d. sweep generator.

The three main requirements for a timing system are

\_\_\_\_\_, \_\_\_\_\_, and \_\_\_\_\_.

Changing the PRF of a radar does/does not affect the pulse width of the transmitter.

List at least four circuits that might be triggered by the timer.

- a. \_\_\_\_\_ c. \_\_\_\_\_
- b. \_\_\_\_\_ d. \_\_\_\_\_

1. The energy of a received signal is generally of low amplitude, often a picowatt or less. Consequently, if all other factors being equal, the efficiency of a system is dependent upon the efficiency of the receiver. This means that a relatively small increase in receiver efficiency may extend the maximum range of a radar to a greater extent than a large increase in transmitter power.
2. For example, suppose we increase the sensitivity of a receiver by 3 db: This means that a signal could be half as large as before, and still be detected with a usable return. In order to realize the same range by increasing transmitter power, it would require an increase of four times the original output power.
3. In general, the amplifiers in use today have the ability to detect and amplify these minute returns. The problem then, is to reduce the noise seen by the amplifier to a level that will cause the signal to appear large by comparison. Since atmospheric noise is always present, there is little that can be done to eliminate it. The major area of research then, is about reducing the internally-generated noise.

## B. Circuitry requirements

1. The receiver of a radar system is made up of several separate circuits. These include the mixer, intermediate-frequency amplifiers, detector, and video amplifier.
2. There are in addition to the basic requirements several circuit-improving devices, such as regenerative amplifiers to increase the signal's amplitude, applying it to the receiver, and automatic frequency controlling circuits to ensure that the receiver is always tuned properly.

Because of the high internal noise generated by tubes at very high frequencies, it is impractical to amplify signals at the frequencies generated by the magnetron. Since the first stage of amplification of a receiver will set the signal-to-noise ratio, r-f energy in the "S" band and above is generally converted to a lower intermediate frequency before amplification takes place. So, when the energy has been reflected from a target and returned back down a waveguide, it is channeled to a crystal, or pair of crystals, reaching this point at the same time as energy from a local oscillator, much the same as in an ordinary superhet radio. The local oscillator signal is usually either 30 MHz above or below the incoming r-f signal, so that when the two mix in the crystals, the 30 MHz signal will be the proper frequency to be amplified by the intermediate-frequency amplifiers. 30 MHz has been selected as a compromise to obtain high gain and a wide bandwidth at an optimum signal-to-noise ratio.

Of course, when the transmitter emitted its high-power energy in the beginning, some means had to be employed to prevent this high power from entering the receiver and blocking the amplifiers and possibly burning out the crystals. This is where the duplexer is employed. When the transmitter fires, the TR tube ionizes, the ATR tube ionizes, and the energy traveling down the waveguide sees nothing but a smooth wall until it is emitted from the antenna. Then, after the transmitter is no longer energized, the TR tube and ATR tube deionize and, as the energy returns, it sees a low-impedance path to the receiver crystals. The ATR tube serves to reflect a high-impedance block at the entrance of the receiver channel to prevent the returning energy from traveling on down the waveguide and being expended in the magnetron.

The balanced mixer, sometimes called the "Magic Tee" mixer, plays a very important part in improving the receiver operation. A balanced mixer has the ability, through its design, to eliminate the local oscillator noise. This is actually accomplished in the load (output) of the mixer. The phase relationship of the r-f energy from the local oscillator is such that resultant voltages of local oscillator and local oscillator noise

## B. I-F amplifiers

1. The first stage of the i-f strip is the determining factor of the signal-to-noise relationship, but after the signal is amplified past the first stage, the addition of minute noise will have minimum effect; therefore, special consideration must be given to the first stage.
2. Triodes are preferred over pentodes where low noise is important; however, the triode has other disadvantages caused primarily by the feedback through the grid capacity. If the load resistance of the triode were made large enough to provide useful amplification, the interelectrode feedback would cause the tube to oscillate. The circuit design of the first-stage amplifier is concerned with the neutralization of the feedback to provide stable operation, yet provide sufficient gain. There are three basic methods of neutralizing a triode in a circuit, depending upon whether the cathode, grid, or plate is grounded. When using 6X4 tubes in each of the three ground configurations, there are nine possible combinations. The best of these combinations is obtained with a grounded-cathode triode, followed by a grounded-grid triode, a configuration known as a cascode amplifier. The grounded second stage loads the first stage so that the first stage has a gain of unity and neutralization is not required. The second triode is necessary in order to achieve gain. By operating this second stage in a grounded-grid configuration, it provides its own input-to-output isolation. Special cascode amplifiers have been developed which provide for the degeneration of noise through a band-reject feedback filter. The cascode amplifier provides the stability and linearity of a pentode and the low noise figure of a triode.
3. Let us next discuss the linear, conventional i-f amplifier. Actually, this amplifier, other than its wide-bandpass, is not much different from the conventional i-f amplifier in a radio receiver. Of course, there are more stages, because greater

at least two of the i-f stages after the first stage. This is necessary to have enough control to reduce the gain of large signals. Controlling the gain of the i-f amplifiers will vary their selectivity. If the receiver gain is adjusted sufficiently high to observe distant targets, serious overloading, with accompanying loss of discrimination, will result for nearby targets in the sea-clutter area. On the other hand, if the receiver gain is adjusted for best results in the sea-clutter area, distant targets may not be visible. The STC (sensitivity time control) circuit automatically reduces the gain of the receiver to a suitable value after the transmitted pulse for a period of time. This reduction in gain decays at an RC rate, increasing the gain for more distant targets.

Another method of improving the action of the i-f amplifier is "Instantaneous Automatic Gain Control" (IAGC). Its action is to reduce the gain of the i-f amplifier by applying a bias voltage to the grids of the i-f amplifiers. The reduction in the i-f signal occurs almost instantly with the reception of a large signal, except for a very small delay introduced by a resistor and capacitor put in for this purpose, which is necessary for optimum operation against sea return. Thus, each received signal block is reduced sharply and effectively narrowed by the automatic back-bias circuit. This reduces signal smearing, particularly on sea-clutter, which consists of signal blocks that illuminate a large area on the screen. Although the desired signal is also suppressed, its recurrence at the same instant and at the same spot on the indicator screen for each scan causes it to have an average illumination which is constant and reasonably bright. The undesired signals, such as sea return or jamming, are continually varying in nature and do not occur at the same points on the sweep for each scan. Consequently, the average illumination and average signal strength for such an area are reduced, while the small target stands out.

IAGC action is applied, usually, to the last half of the i-f strip, with each i-f stage having its own IAGC circuit. Since this action may not be desired at all times, some means of switching the circuit in and out

2. If the RC time of the detector were made long, the maximum amount of signal out, the trailing the signal would be stretched out, producing a called Time Base Distortion. This results in of range resolution and possibly the loss of s targets in the trailing edge of a larger target. time were made short to overcome this, the average put of the detector would be low, reducing its efficiency.

#### D. Video circuits

1. The video circuits of a radar receiver should bandwidth of from 20 Hz to 5 MHz. This is so sharp leading and trailing edges as well as the top portion of the returned echo may be amplified equally. The returned echo will always have a fundamental frequency equal to the fundamental of the transmitted pulse. Radar returns from very large targets such as land masses, would have a very long time constant and therefore a low fundamental frequency component. The receiver video amplifiers should be able to amplify all target returns equally.
2. In the video circuit, there is a special circuit is used to assist the operator in separating the (short time base) targets from the large (long time base) targets, called the "fast-time constant" circuit. The FTC circuit is a short-time constant RC network at the input of the first video amplifier. When a block of video is sent through the FTC circuit, the leading edge would cause an output because of the short time constant. A signal on the display would be a large one, because only the leading edge of each target return will produce an indication.

#### E. Automatic Frequency Control (AFC)

1. In any superheterodyne receiver, it is desirable to maintain the local oscillator one i-f away from the received signal. In radar applications, using the received signal as the reference has disadvantages such as:

a. The system is subject to control by spurious signals.

are channel, using a controlled sampling of the transmitted frequency as the reference, is generally used. (See figure 1.)

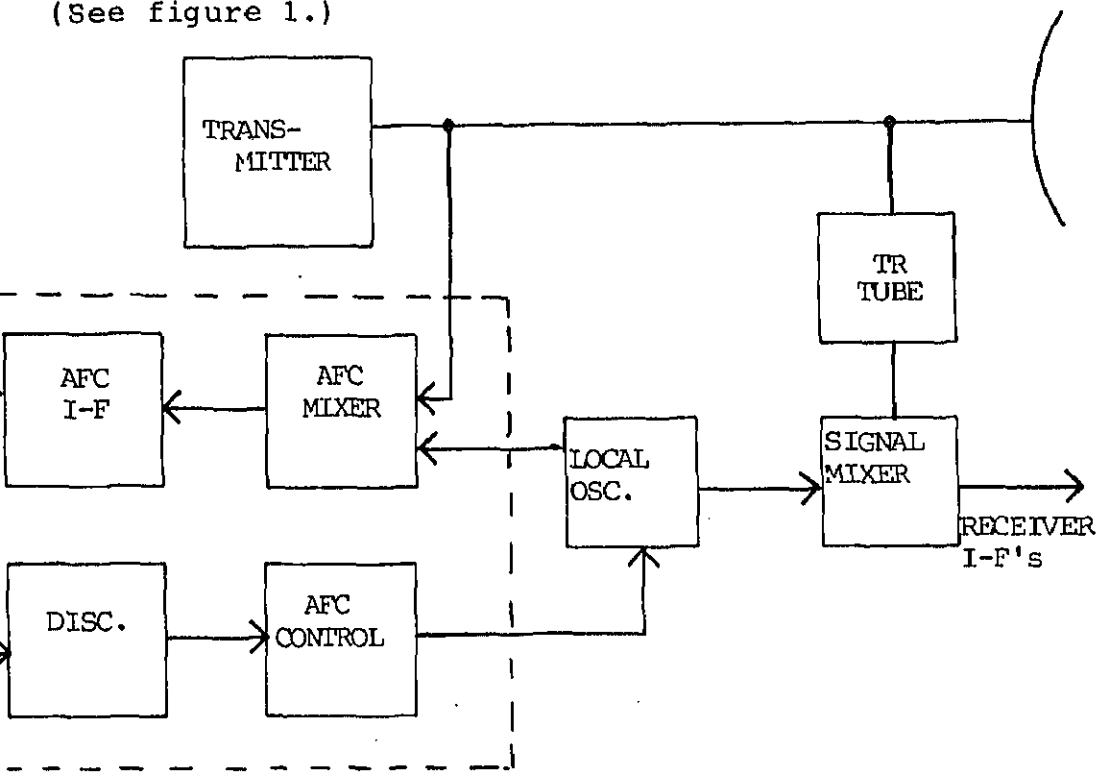


Figure 1

An automatic frequency control circuit is an arrangement for maintaining the constant one-i-f difference between the transmitter and the local oscillator, despite effects tending to shift these frequencies. The effects include temperature changes in both the transmitter and the local oscillator and transmitter load-impedance changes caused by antenna rotation.

The pulling of the magnetron, by reactance being coupled back into the oscillator circuit due to antenna rotation, has been alleviated in some of our more modern radars by buffering the magnetron from the load with a small ferrite load isolator as well as ferrite duplexers with their inherent load isolation.

The following chart shows typical frequency deviation to be expected in magnetrons and klystrons:

ENVIRONMENTAL FACTOR	MAXIMUM DEVIATION FREQUENCY
Scatter of magnetrons and klystrons received from manufacturer	+ 50
Warm-up of radar set	+ 1.5
Temperature	+ 15
Pressure (0-50,000)	- 2.5
Pushing (+ 10% line voltage)	+ 5.0
Aging	+ 10

5. Tuning errors in the radar receiver degrade the S/N ratio of the radar. Maximum-range performance of the radar is thus a function of the tuning accuracy of the receiver. To obtain the maximum performance of the radar system, the i-f bandwidth must be matched to both the receiver pulse and the tuning error of the receiver.
6. To obtain maximum system performance, a compromise between afc performance and bandwidth must be made to provide maximum S/N ratio. The static accuracy that can be realized in the usual radar is dependent on the accuracy of the reference and the amount of z-f frequency gain it is practical to employ in the feedback loop.
7. The afc system can be broken down into four basic circuits: (Refer to Figure 1.)
  - a. MIXER: Its function is to compare two frequencies and produce the difference frequency as its output.
  - b. AFC I-F AMPLIFIERS: Amplifies the output of the mixer.
  - c. DISCRIMINATOR: Functions as the error detector of the system, producing a voltage out, the magnitude of which is proportional to the deviation of the received frequency from the reference frequency.



crease the original error voltage to zero. The process is similar in principle to a servomechanism in that there must always be a small error to provide a correction voltage, but the error required may be decreased by increasing the amplification between the discriminator and the klystron.

#### AFC Mixer

- a. A small fraction of the transmitter pulse energy is obtained for the afc mixer through a sampling connection in the line between the transmitter and antenna. An r-f attenuator is inserted between this connection and the mixer. The attenuation is usually produced by a section of waveguide below cutoff. The attenuation in db is proportional to the length, and this length is adjusted to give the required fraction of transmitter power at the mixer. The attenuation value is very large, from 75 to 92 db, in order to reduce the transmitter power, ranging from 35 kw to 2 mw, down to the 1 or 2 mw at the crystal.
- b. Output of mixer is difference between transmitter  $f_o$  and local oscillator.

#### I-F Amplifiers (afc)

- a. The purpose of the i-f amplifiers in the afc circuits is essentially the same as that of the main-channel i-f amplifiers.
- b. The bandwidth characteristics will be determined by the requirements of the discriminator circuit, and are usually slightly wider than the discriminator's control range. This is done for the purpose of varying the discriminator's control point without requiring a complete realignment of the i-f section.
- c. AFC i-f amplifiers normally do not require gain control circuits or any special low-noise features of the main-channel i-f amplifiers.

desired zero output when the difference in  
is equal to the desired center frequency

- b. Correct afc action has this important characteristic: When the local oscillator frequency is changed, the voltage change in the discriminator output must be such as to oppose the local oscillator frequency variation.
- c. A direct-coupled amplifier can be added to the system between the discriminator and the oscillator stage to increase loop gain.

## 11. Control circuits

- a. The control circuit, which is the final link in the afc chain, has the function of converting the discriminator voltage into a local oscillator frequency correction. Electro-mechanical tuning are available with the modulated tubes used as radar local oscillator. Electronic tuning is usually adequate to meet afc requirements.
- b. Diode-phantastron afc (hard-tube afc) (Fig. 11-1)

  - (1) This circuit also uses the drift-in theory of operation, with the diode V<sub>1</sub> acting as the search stopper and the free-running phantastron functioning as the slow-sweep generator.
  - (2) If no error is present, the phantastron will execute a series of sawtooth down sweeps separated by moderately long periods. If, during one of the sweeps, a pulse appears at the discriminator output, the phantastron will be stopped as soon as the discriminator crossover frequency is passed.
  - (3) These pulses are coupled to the shunt detector negative clamper and cause it to develop a negative voltage. As soon as the voltage across the diode becomes equal to the negative voltage on the phantastron control grid,

with a gain of about 50.

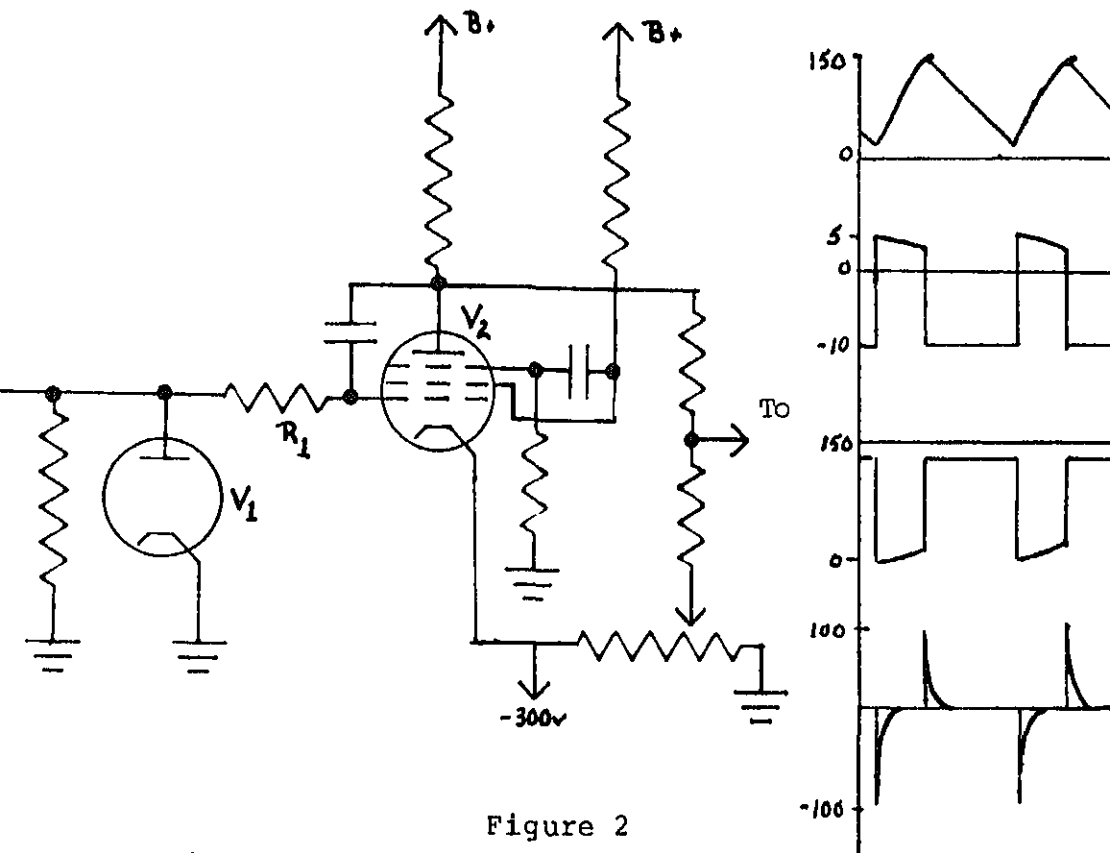


Figure 2

## CONCLUSIONS

The efficiency of the radar system is dependent to a large extent upon the performance of the receiver. And the receiver, to perform at its peak efficiency, utilizes special circuits.

The signal is first mixed in the crystals, amplified by a special low-noise, wide-band (Wallman or Cascode) amplifier and then sent on to the rest of the i-f amplifier chain.

The linear i-f amplifier contains a special circuit called a Sensitivity Time Control Circuit which reduces gain at short ranges.

Then there is "Automatic Back-Bias", which is an instantaneous

will produce the optimum output.

The basic purpose of the synchronizer in a radar system is that of coordination. In order to accurately determine the range of a target, the firing of the transmitter must occur at a specific time, and the ranging and display circuits must be placed in operation at a precise time in order to measure the elapsed time between transmission and reception of the echo pulse.

The synchronizer is often referred to as the "timer", and its specific function is to produce the trigger pulse that starts the transmitter, the sweep circuits, range mark generators, blanking circuits, and the various gating signals that may be required in radar systems.

Timing circuits should meet three basic requirements:

1. Must be free-running (astable) - The timer is the heart of the radar; it must establish the zero reference time and the PRF.
2. Must be stable in frequency (PRF) - The PRF, or its reciprocal, the PRT, must not change between pulses for accurate ranging.
3. Output frequency must be variable - In order to change PRF to some lower value for longer available range, the timer is usually constructed so that the operator may switch to a submultiple of the basic PRF.

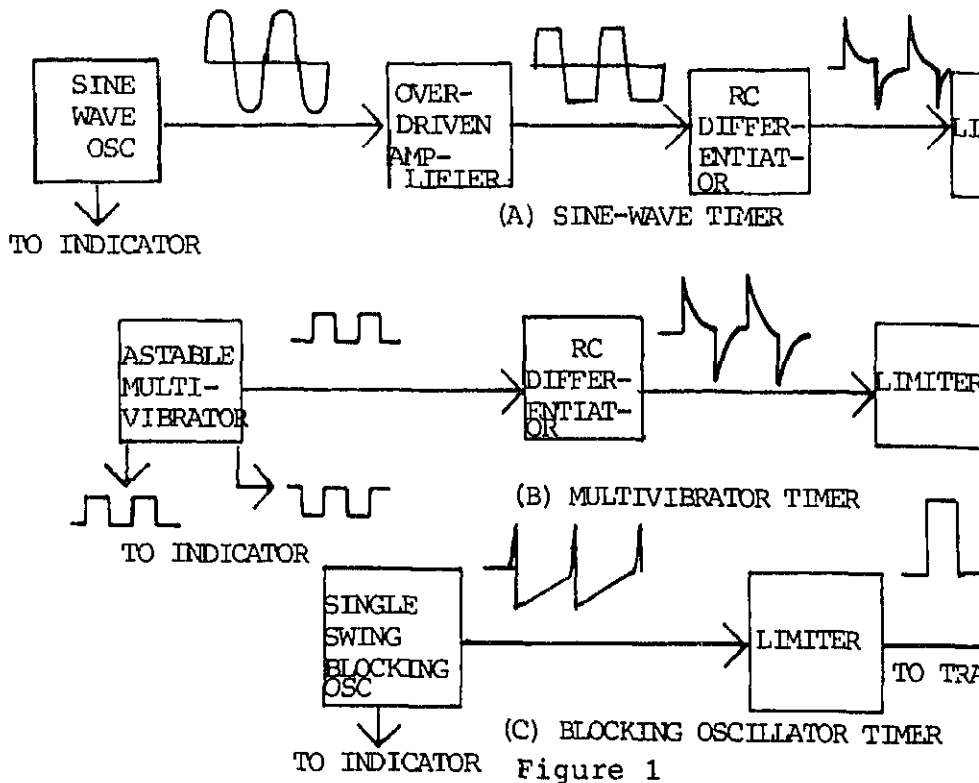
REFERENCE - NAVPERS 10318-D Aviation Electronics Technician  
1 & C

### FORMATION

There are three basic circuits that can meet the above mentioned requirements. They are the sine-wave oscillator, single-swing blocking oscillator, and the master trigger multivibrator.

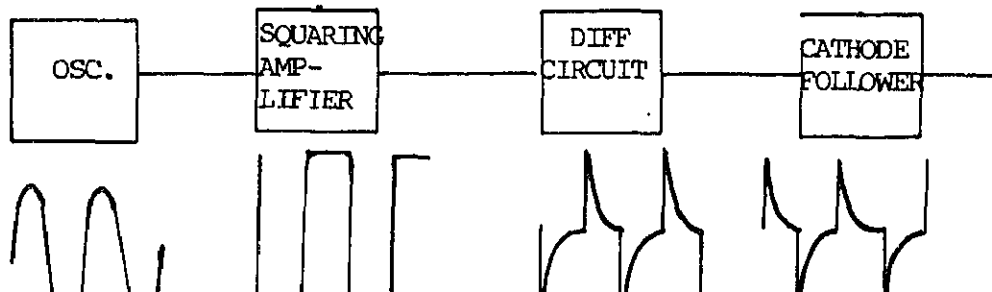
When a blocking oscillator is used as the master oscillator, the output pulses may be obtained directly from the oscillator. When a sine-wave oscillator or a multivibrator is used, pulse-shaping circuits are required to form the necessary timing/trigger pulses.

equally spaced pulses are produced. The repetition rate of each series of pulses is determined by the operating frequency of the master oscillator.



#### D. Sine-wave oscillator type

1. In figure 2, a sine-wave oscillator is used as a timing device. The oscillator may be a wein-rc phase shift type.



- the cathode follower is used as a convenient means to trigger the basic pulse blocking oscillator and provide isolation between the differentiating circuit and the blocking oscillator. The cathode follower may be biased to limit either the positive or negative portions of the differentiated waveform if desired.
5. The basic pulse blocking oscillator is used to form the desired timing pulse shape. The output frequency may be sub-divided to produce lower PRF's for longer range of operation.
  6. The squaring amplifier, differentiating circuit, cathode follower, and basic pulse-blocking oscillator form the basic pulse circuit which determines shape, amplitude, and recurrence time of the timer pulses.
  7. One disadvantage of the sine-wave type timing device is that it requires a large number of pulse-shaping circuits to produce the desired output pulse shape. Therefore, this type is seldom found in modern radar systems.

### Multivibrator Timer

1. Figure 3 is a typical multivibrator timing circuit.

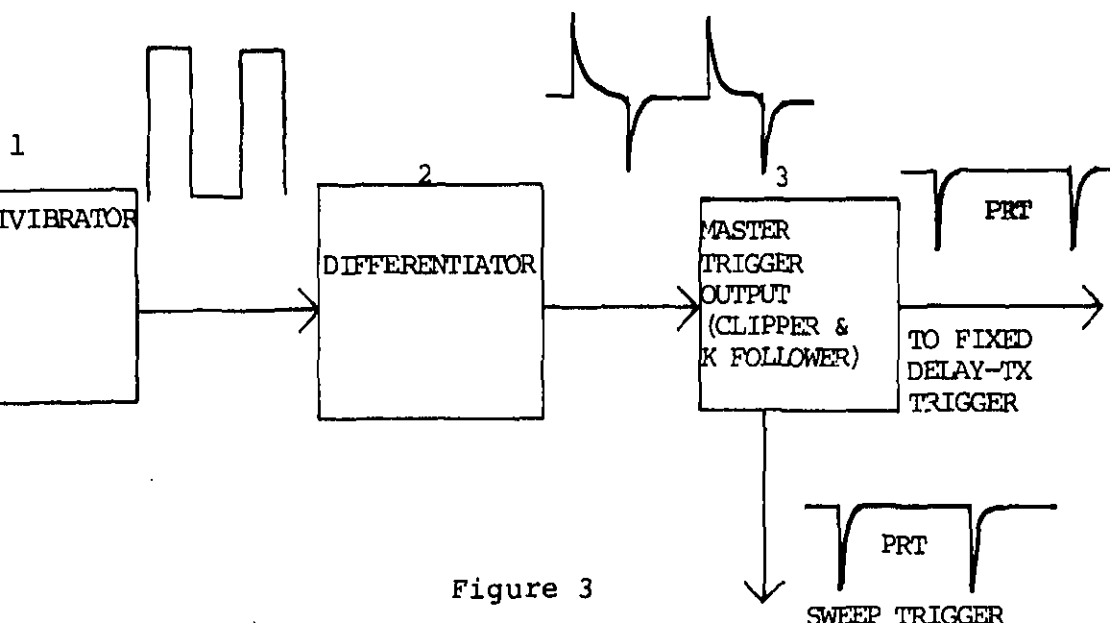


Figure 3

4. Output circuit is usually a cathode follower limit one half of the waveform.

#### F. Single Swing Blocking Oscillator Type

1. Figure 4 illustrates a SCBO type timer circuit. PRF is determined by the R-C network of circuit.

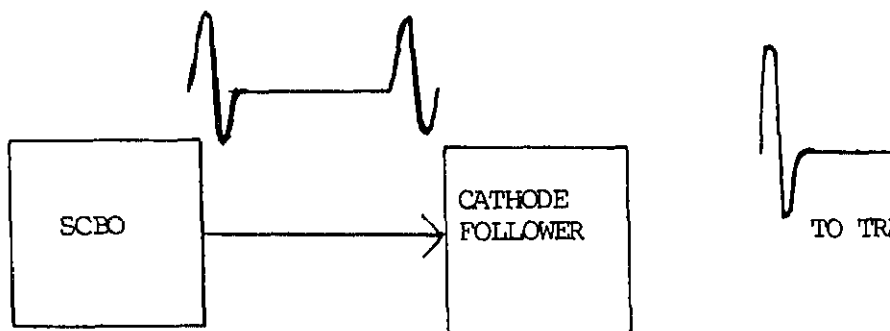


Figure 4

2. When the transmitter is triggered by the trigger is also supplied to the sweep generator, CRT unblanking circuit, and the range meter.
  3. Output waveform may be limited either positive or negative by the bias arrangement on the cathode follower.
  4. The advantage of the SCBO type is that a single swing is produced without additional shaping circuitry. The pulse may be applied directly.
- G. An additional type of timer that may be employed is the crystal-controlled oscillator. This type is used when precise PRF's are required at a particular



Fixed Delay Modulator Trigger - Used with most electromagnetic deflection systems for the purpose of delaying the transmitter's firing until the sweep current waveform has had an opportunity to become stabilized. This delay is usually less than 10 sec.

Range Marker Generator - A precision oscillator that is gated on at the same time as the transmitter is fired. Output is limited, and caused to produce a range mark at the proper time. This circuit is usually made capable of producing several different markers (1 mile, 5 mile, etc.).

Sweep Generator - Produces a linear sawtooth waveform to cause electron beam of CRT to be deflected linearly with elapsed time since firing of the transmitter.

Indicator Unblanking Circuit - Used to unblank the CRT at the desired time in respect to the transmitter's firing. This may be caused to happen prior to, or delayed in respect to, the transmitter trigger, depending upon the tactical situation.

LESSON TOPIC LEARNING OBJECTIVES:

- 11.6.1 Given statements concerning advantages and of "A" scan to "B", "PPI", and "E" scan, select the correct statement.
- 11.6.2 Given statements concerning information presented of modulation, advantages of "B" scan presented compared to "A", "PPT", and "E" scan, select the correct statement.
- 11.6.3 Given statements concerning information presented of modulation and stabilization used in a "B" scan, select the correct statement.
- 11.6.4 Given statements concerning information presented of modulation, and reason for using a sector scan, select the correct statement.
- 11.6.5 Given statements concerning presented, type of modulation, and reason for using an "E" scan presented, select the correct statement.

STUDY ASSIGNMENT:

- Read:
- 1. NAVPERS 10387-A Aviation Fire Control Technician 3 & 2, pp. 255-265.
  - 2. NAVTRA 10318-D Aviation Electronics Technician 1 & C, pp. 273-313.

COMPLETE: Student Activity Guide 11.6.1S

STUDY QUESTIONS:

- 1. What are the applications for the different types of radar indicators?
- 2. What type deflection methods do the different types of radar indicators use?



- d. range.
2. In a Type "A" scan, the receiver's output is not related to which component of the indicator?
    - a. vertical deflection plates
    - b. horizontal deflection plates
    - c. cathode
    - d. control grid
  3. Without auxiliary instruments, the primary disadvantage of a Type "A" scan is that no \_\_\_\_\_ information is available.
  4. In a Type "B" scan, the indicator plots one variable against another. Those two variables are:
    - a. time vs. range.
    - b. time vs. azimuth.
    - c. range vs. relative altitude.
    - d. range vs. signal intensity.
  5. Video data is supplied to the indicator and superimposed on the display by \_\_\_\_\_ modulation of the electron beam.
  6. Usually, \_\_\_\_\_ is presented vertically and range is presented horizontally on a Type "B" scan.
  7. In a Type "B" scan, the horizontal location of the target indicates:
    - a. the range of the target.
    - b. the relative altitude of the target.
    - c. the relative azimuth of the target.
    - d. the location of the antenna in respect to the target boresight.

- . the nose of the aircraft.
- . the position of the antenna.
- . true heading of the aircraft.
- . true north.

North stabilization requires an additional input to the synchro resolver to reposition the stators as the aircraft maneuvers. This input is from the aircraft's:

- . compass system
- . radar's slant range.
- . true air speed indicator.
- . attitude indicator.

In ground stabilization, the origin represents the \_\_\_\_\_ of the aircraft.

- . attitude
- . speed
- . position
- . altitude

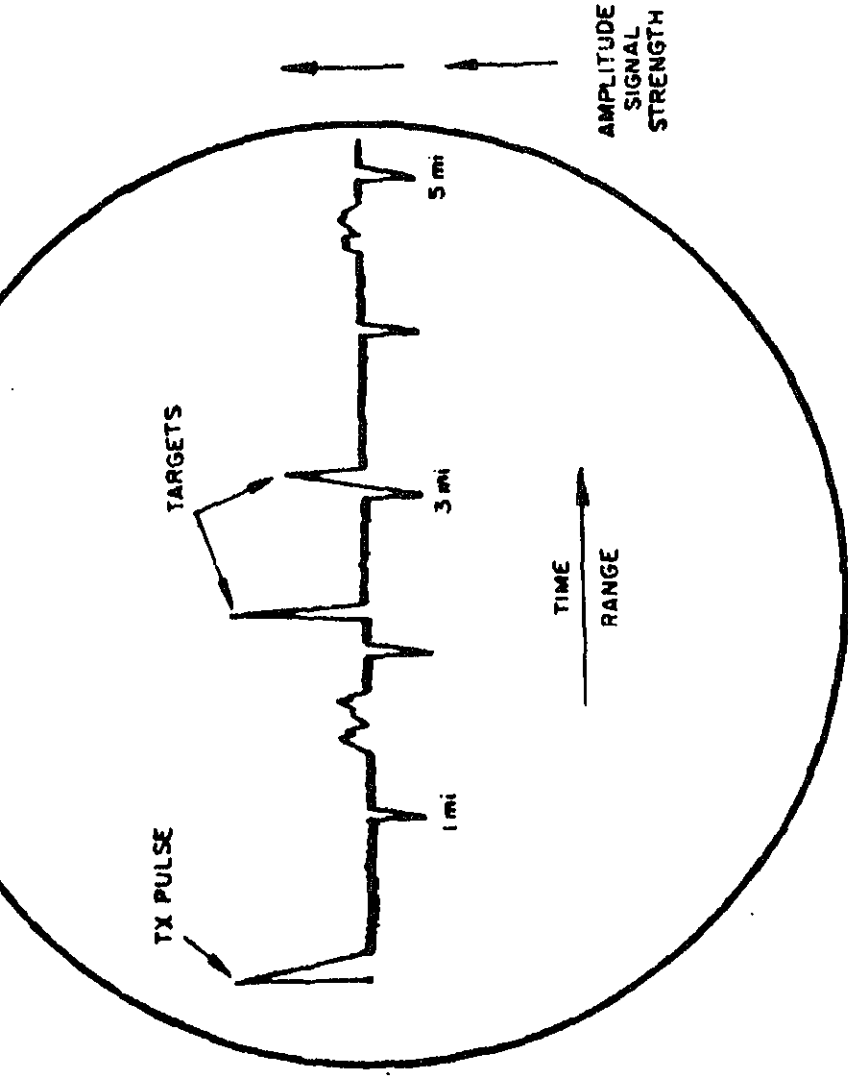
In a "PPI" scan, the indicator displays:

- . range and the bearing of the returns.
- . range and the elevating of the returns.
- . range and relative altitude of the returns.
- . azimuth and the elevation of the returns.

The "E" scan indicator is primarily used with:

- . a bomb director is primarily used with:
- . a MTI radar.
- . a height finding radar
- . a side looking radar.





"A" SCAN PRESENTATION

VIDEO FROM

618  $\mu$ sec

618  $\mu$ sec

618  $\mu$ sec

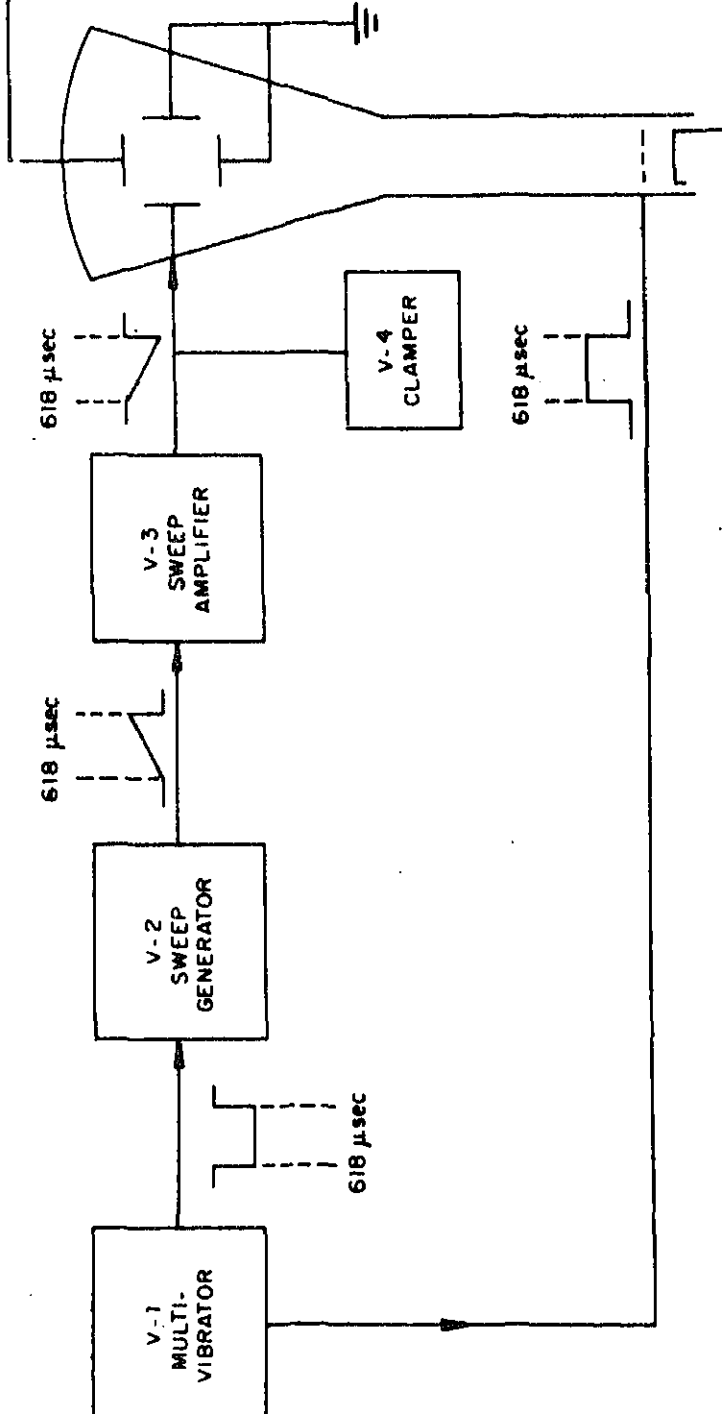
618  $\mu$ sec

V-3  
SWEEP  
AMPLIFIER

V-2  
SWEEP  
GENERATOR

V-1  
MULTI-  
VIBRATOR

V-4  
CLAMPER





TARGETS TO THE LEFT

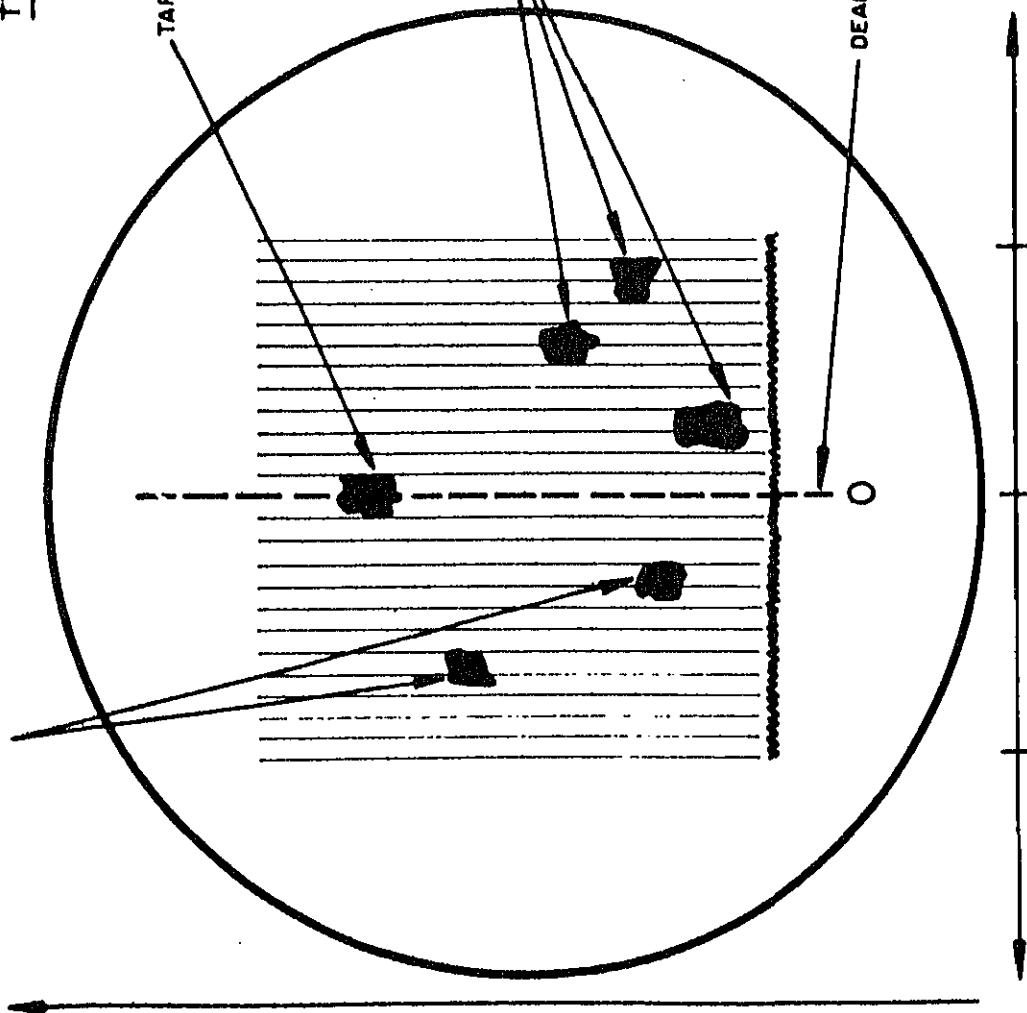
TARGET DEAD AHEAD

RANGE

TARGET

DEAD AHEAD

AZIMUTH



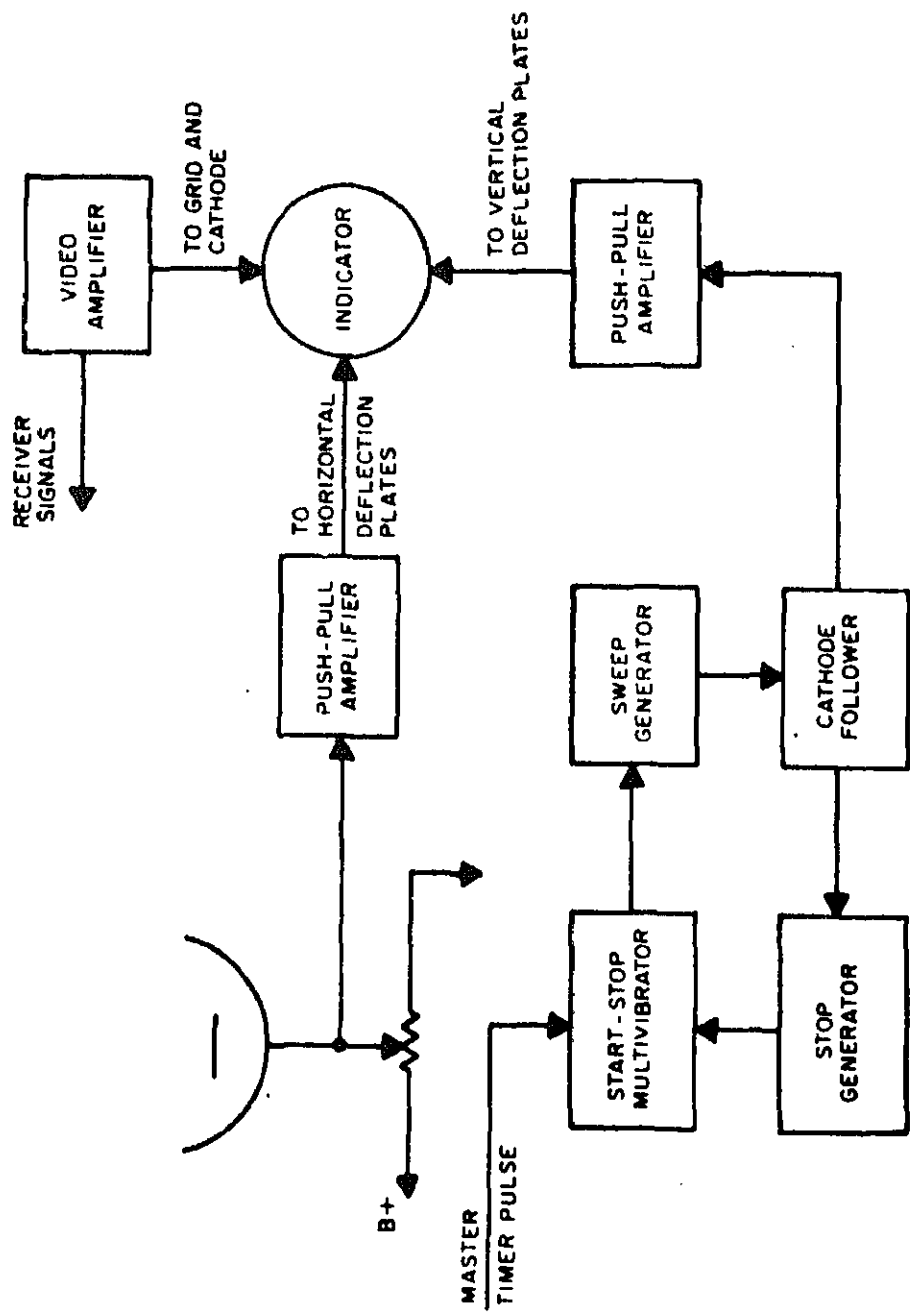
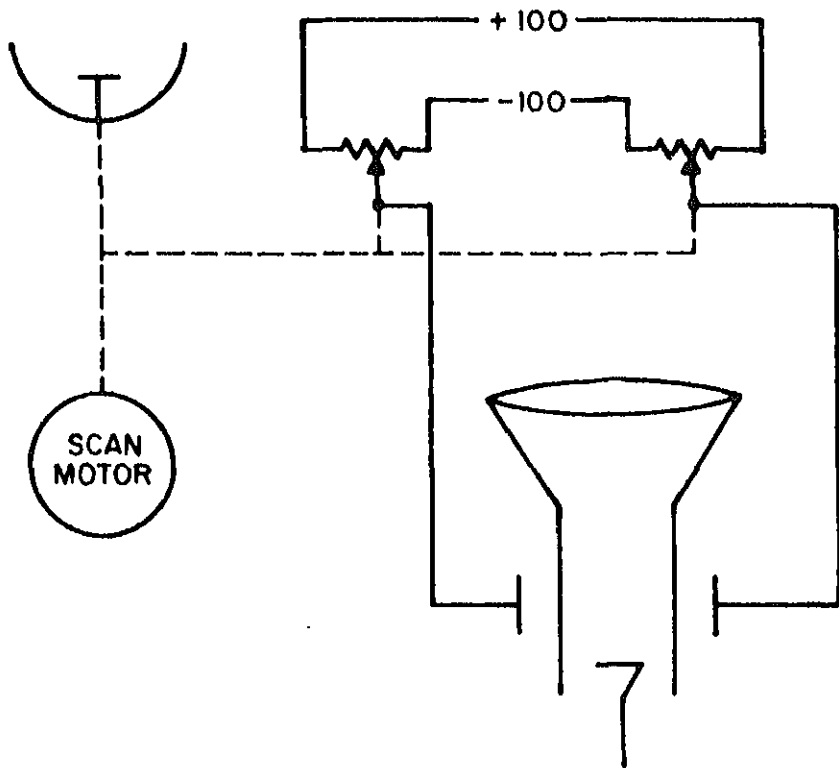
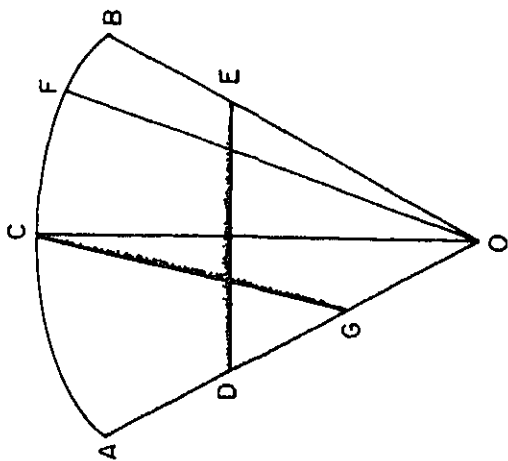
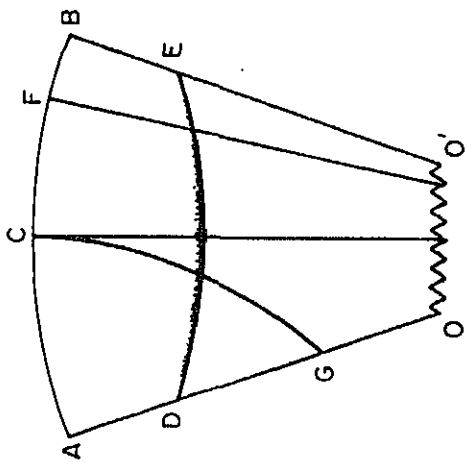
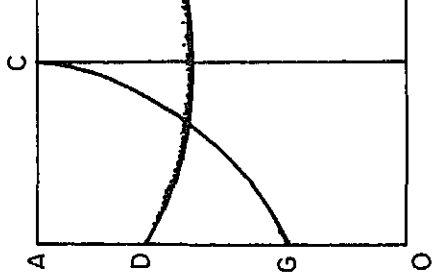
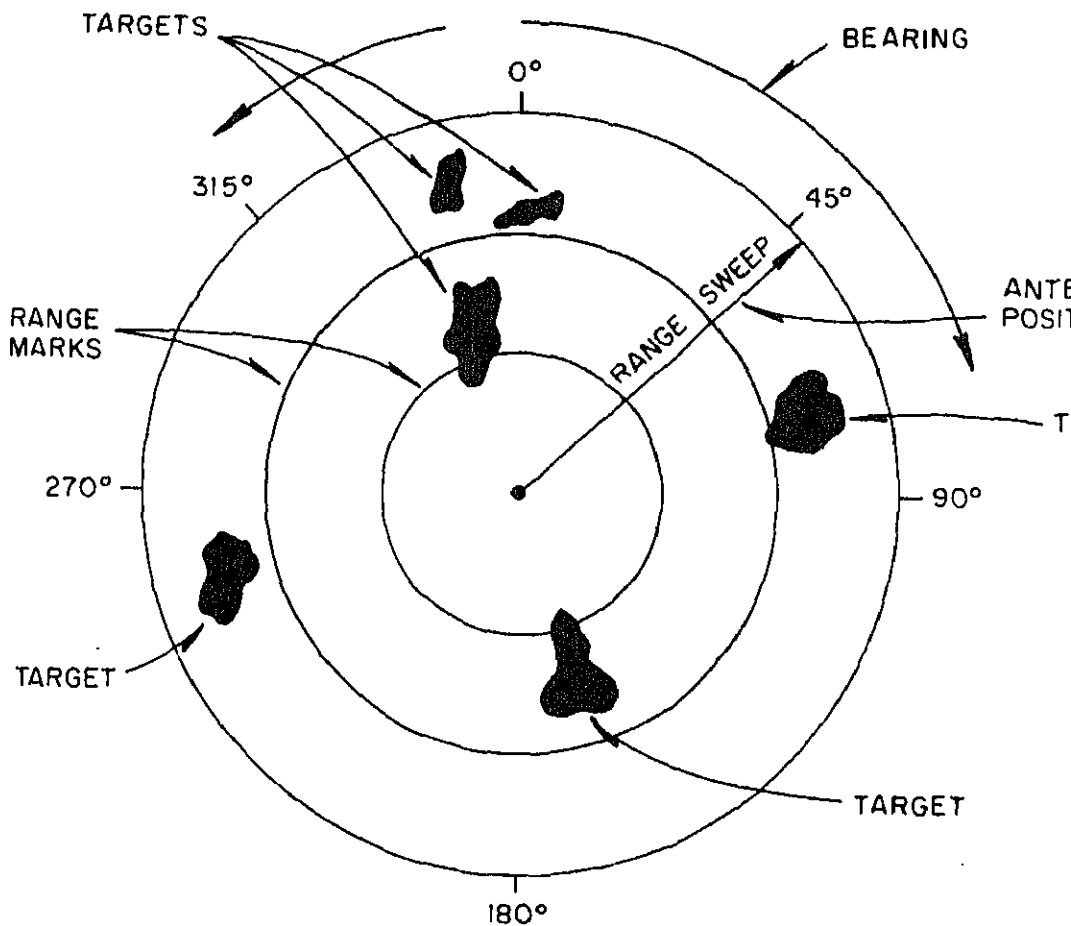


FIGURE 4

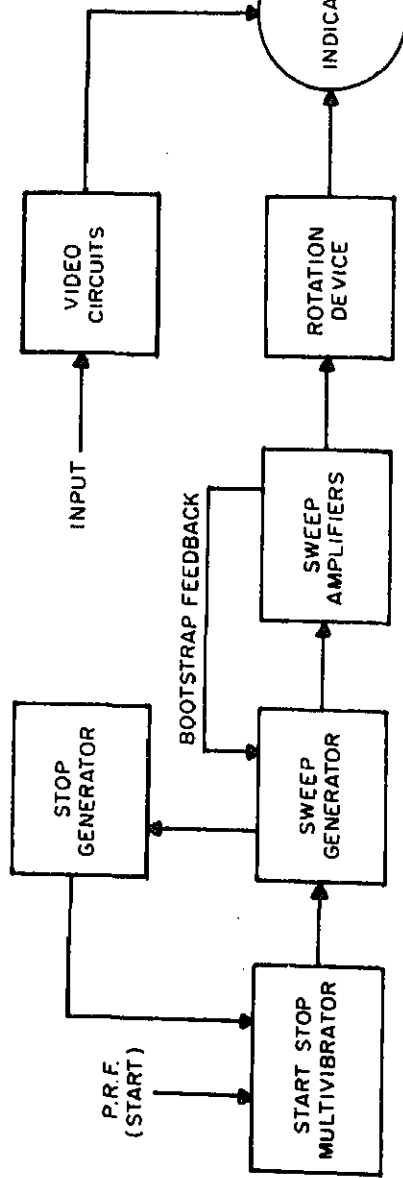


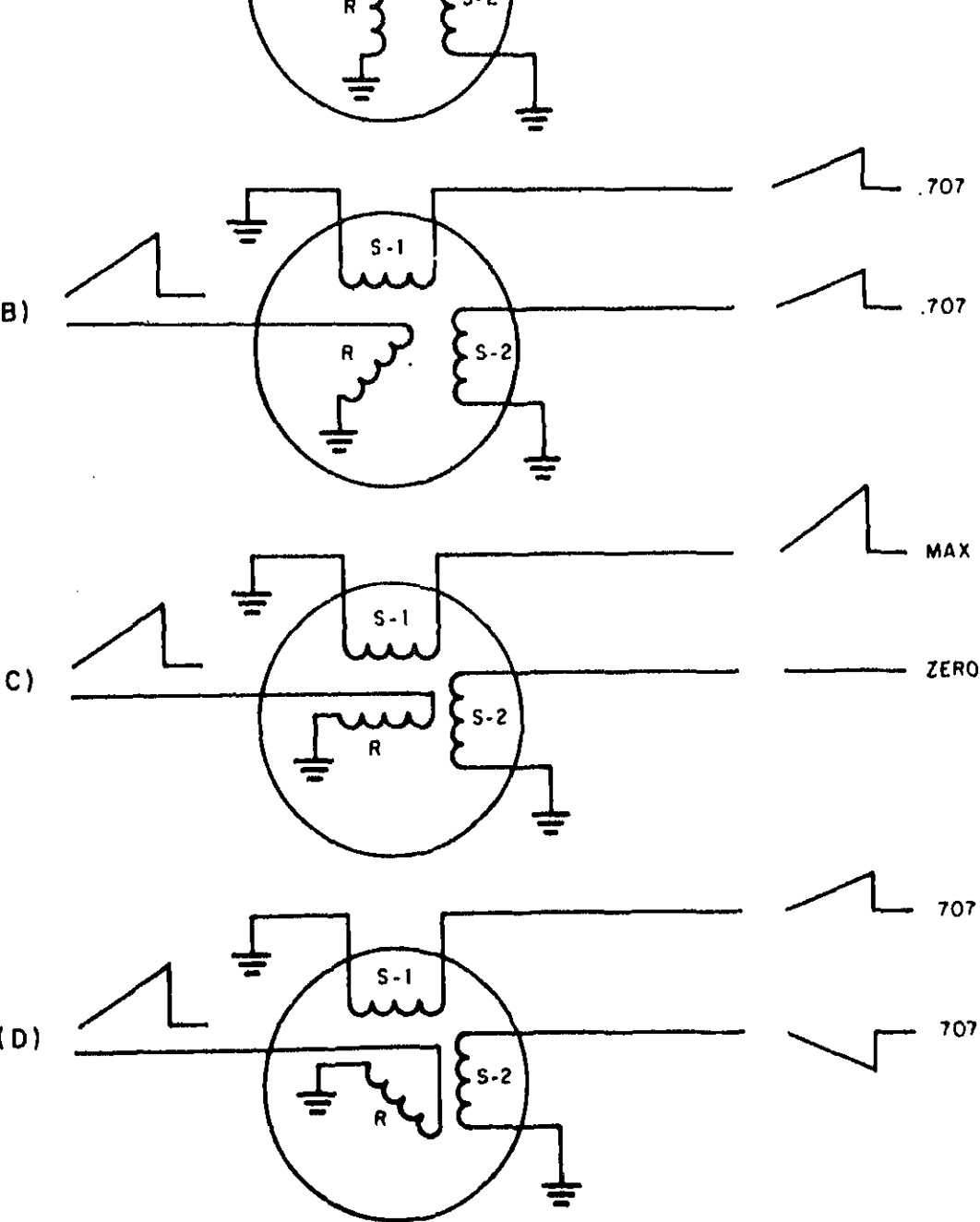
AZIMUTH DEFLECTION POTENTIOMETERS



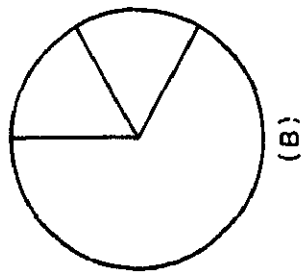
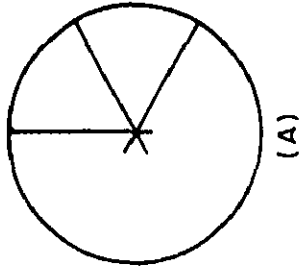


PPI-SCAN PRESENTATION  
(Map-like picture)

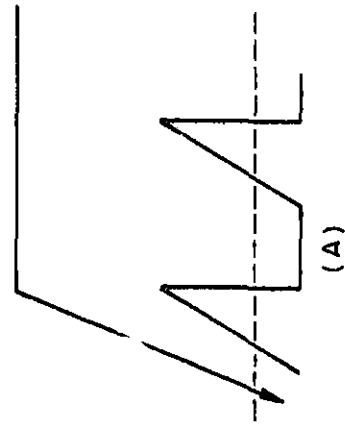




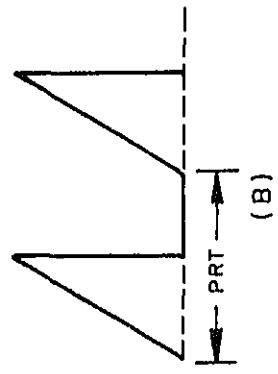
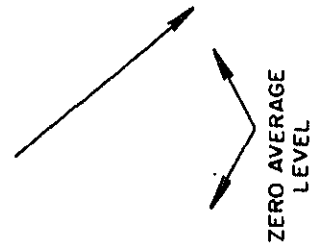
SYNCHRO RESOLVER FOR ROTATING SWEEP



START OF SWEEP AND  
RANGE ZERO



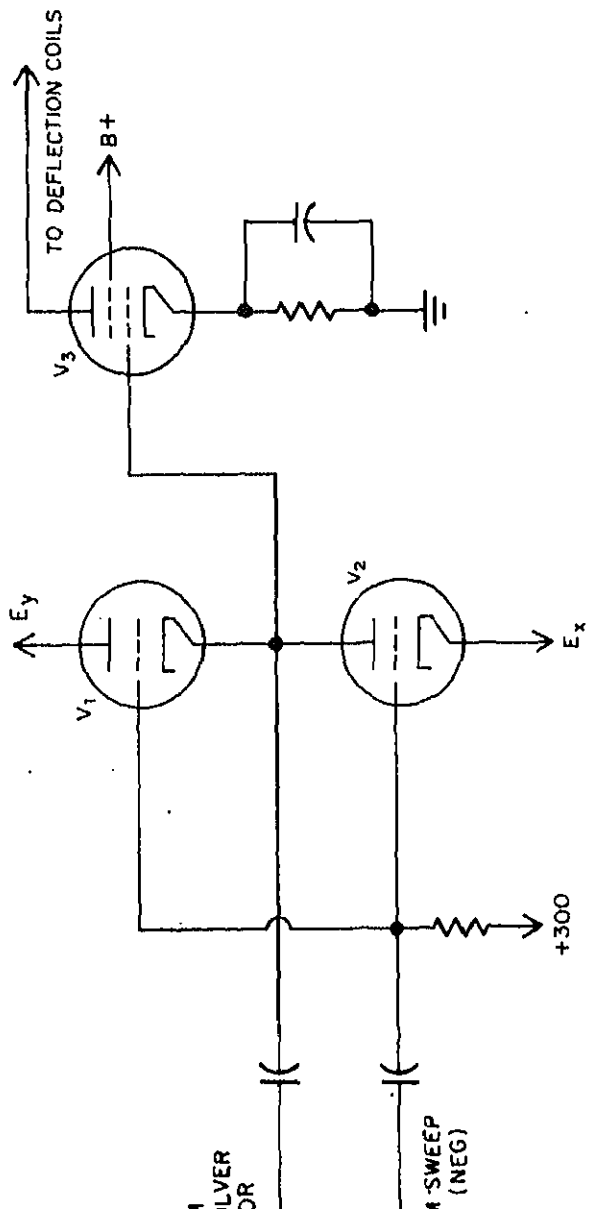
SWEEP WAVEFORM WITHOUT  
COMPENSATION



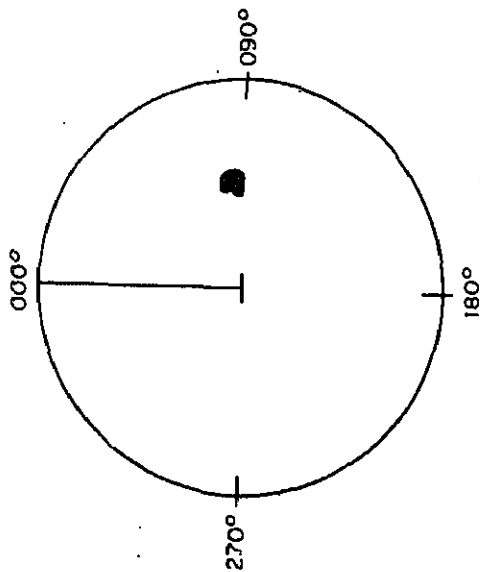
CORRECTLY COMPENSATED  
SWEEP WAVEFORM

PRT

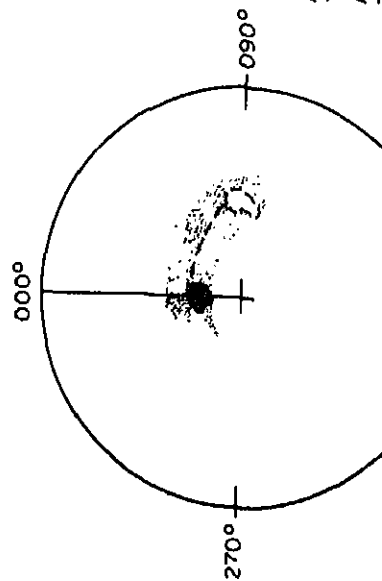




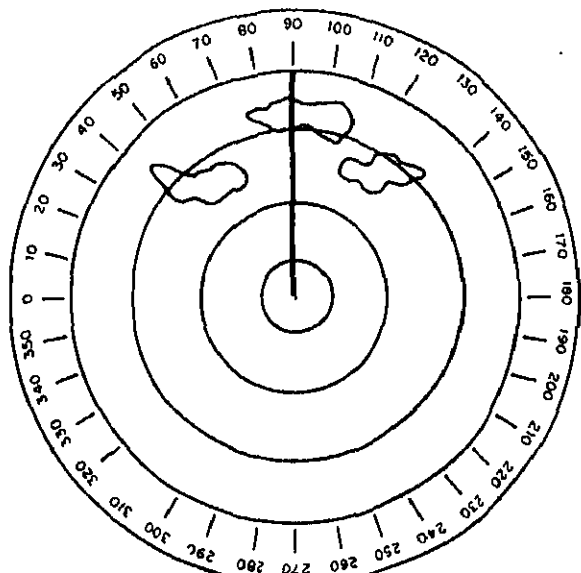
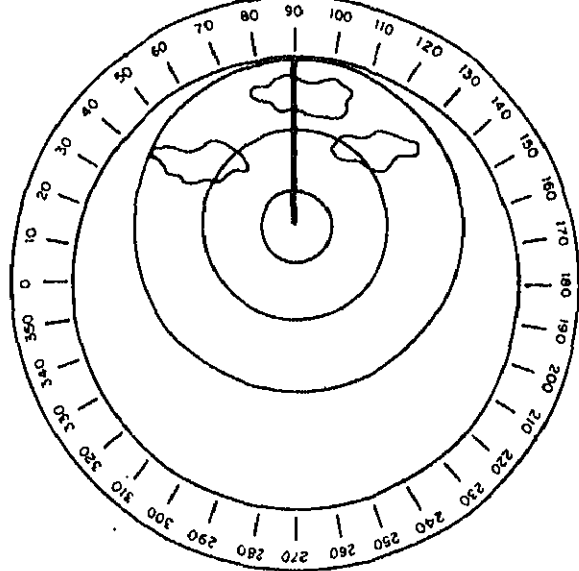
CLAMPER CIRCUIT

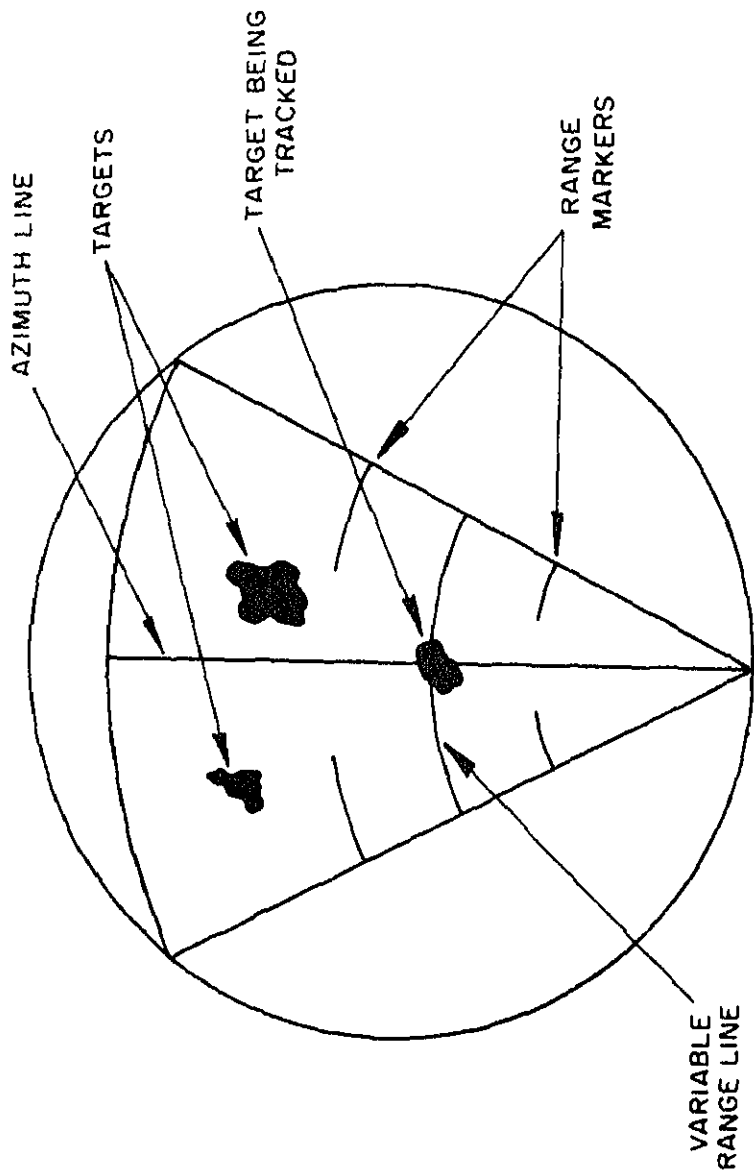


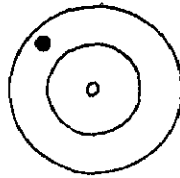
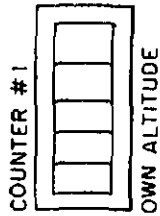
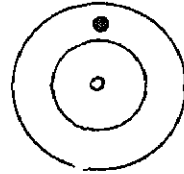
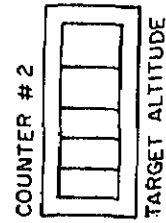
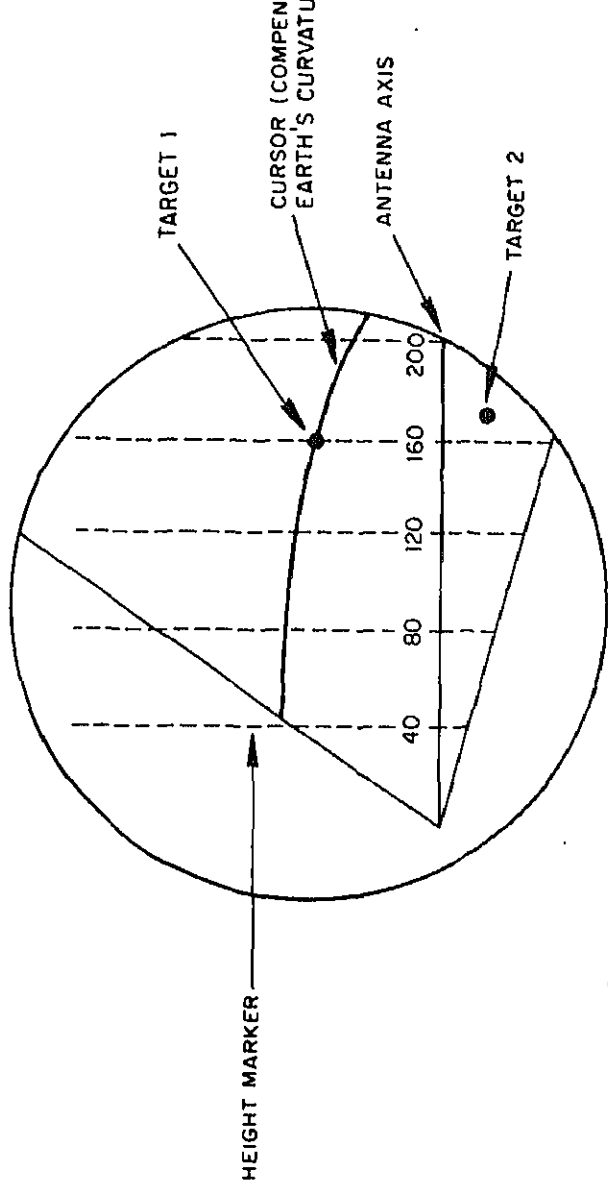
AIRCRAFT HEADING 000°  
 TARGET OFF STARBOARD  
 WING.



AIRCRAFT HAS MADE 90°  
 TURN TO STARBOARD.  
 AIRCRAFT HEADING 090°;







- 11.7.1 Given statements concerning target parameters of a tracking radar, select the correct statement(s).
- 11.7.2 Given statements concerning the advantages and disadvantages of a search mode on a tracking radar, compared to separate radars, select the correct statement(s).
- 11.7.3 Given statements concerning the principles of a sequential lobing tracking radar, select the correct statement(s).
- 11.7.4 Given a block diagram of a conical-scan tracking radar, select the correct statement(s).
- 11.7.5 Given statements concerning the advantages of monopulse techniques over sequential lobing techniques, select the correct statement(s).
- 11.7.6 Given statements concerning range determination derived from single plane sensing and the basic monopulse radar, select the correct statement(s).
- 11.7.7 Given a block diagram of a two coordinate amplitude monopulse tracking radar and statements concerning the channel is used for elevation and azimuth angle determination select the correct statement(s).
- 11.7.8 Given statements concerning the operational characteristics of a track-while-scan (TWS) radar, select the correct statement(s).

#### STUDY ASSIGNMENT

- Read:
- 1. Aviation Fire Control Technician 3 & 2 NAVTRA 10387B pages 176-182.
  - 2. Information Sheet 11.7.1I "Radar Track

Complete: Student Activity Guide 11.7.1S

STUDY QUESTIONS: None

is the minimum number of lobes required to provide two  
ordinate angular error information in a sequential lobing  
king radar?

type of signal waveform does the concial scan error signal  
mble?

is the difference between monopulse and sequential lobing  
niques?

h channel of a single plane sensing monopulse provides range  
rmation?

Sum  
Difference  
Both A and B  
Neither A or B

many receive channels are there in a dual plane sensing  
pulse?

1  
2  
3  
4

ck while scan radar requires \_\_\_\_\_ consecutive contacts to  
ire a track and \_\_\_\_\_ consecutive blank scans to terminate

1. Introduction to Radar Systems, Skolnik, McGraw-Hill, Chapter 5
2. NAVEDTRA 10387B pages 176-182

## INFORMATION:

### I. TRACKING RADAR

#### A. Tracking With Radar

A tracking-radar system measures the coordinates of a target and provides data which may be used to determine its path and to predict its future position. All of the available radar data -- range, elevation, azimuth angle, and doppler frequency shift -- may be used in predicting future position; that is, a radar may track a target in range, in angle, in doppler, or with any combination of these. Almost any radar can be considered a tracking radar if its output information is processed properly. In general, it is the method by which angle tracking is accomplished that distinguishes what is normally called tracking radar from any other radar. It is also possible to distinguish between a continuous tracking radar and a track-while-scan (TWS) radar. The former supplies continuous tracking data on a particular target, while the latter supplies sampled data on one or more targets. In general, the continuous tracking radar and the track-while-scan radar employ different types of equipment.

The antenna beam in the continuous tracking radar is positioned in angle by a servomechanism actuated by the target signal. The various methods for generating the tracking signal may be classified as sequential lobing, conical scanning, simultaneous lobing or monopulse. The range and doppler frequency shift can also be continuously tracked by servo-control loop actuated by an error signal in the radar receiver. The information available from a tracking radar may be presented on a cathode-ray tube display for action by an operator, or may be processed by an automatic computer which determines the target's position and calculates its probable future course.



necessary to position the tracker on the target. A search radar, when used for this purpose, is called an acquisition radar. The acquisition radar designates targets to the tracking radar by providing the coordinates where the target are to be found. The tracking radar acquires a target by performing a limited search in the area of the designated target coordinates.

The scanning fan-beam search radar can also provide tracking information to determine the path of the target and predict its future position. Each time the radar beam scans past the target, its coordinates are obtained. If the change in target coordinates from scan to scan is not too large, it is possible to reconstruct the track of the target from the sampled data. This may be accomplished by providing the PPI-scope operator with a grease pencil to mark the target pips on the face of the scope. A line joining those pips that correspond to the same target provides the target track. When the traffic is so dense that operators cannot maintain pace with the information available from the radar the target trajectory data may be processed automatically in a digital computer. The availability of small, inexpensive minicomputers has made it practical to obtain target tracks not just target detections, from a surveillance radar. Such processing is usually called ADT (automatic detection and track). When the outputs from more than one radar are automatically combined to provide target tracks, the processing is called ADIT (automatic detection and integrated track) or IADT (integrated ADT).

A surveillance radar that provides target tracks is sometimes called a track-while-scan radar. This terminology is also applied to radars that scan a limited angular sector to provide tracking information at a high data rate on one or more targets within its field of view. Landing radars used for GCA (ground control of approach) and some missile control radars are of this type.

When the term tracking radar is used in this information sheet it generally refers to the continuous tracker, unless otherwise specified.

radial component to position the antenna so that the angular error is zero. When the angular error is zero, the target is located along the reference direction.

One method of obtaining the direction and the magnitude of the angular error in one coordinate is by alternately switching the antenna beam between two positions. This is called lobe switching, sequential switching, or sequential lobe switching. Figure 1 is a polar representation of the antenna beam (minus the sidelobes) in the two switched positions. The plot in rectangular coordinates is shown in Figure 1b. The error signal obtained from a target not on the switching axis (reference direction) is shown in Figure 1c. The difference in amplitude between the voltages obtained from the two switched positions is a measure of the angular displacement of the target from the switching axis. The sign of the difference determines the direction the antenna must be moved in order to align the switching axis with the direction of the target. When the voltages in the two switched positions are equal, the target is on axis and its position may be determined from the axis direction.

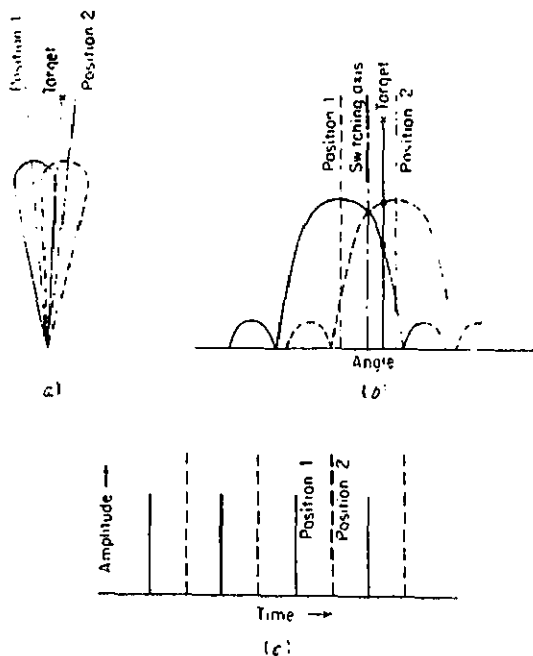


Figure 1

stepped in this five-feed arrangement.

One of the limitations of a simple unswitched nonscanning pencil-beam antenna is that the angle accuracy can be no better than the size of the antenna beamwidth. An important feature of sequential lobing (as well as the other tracking techniques to be discussed) is that the target-position accuracy can be far better than that given by the antenna beamwidth. The accuracy depends on how well equality of the signals in the switched positions can be determined. The fundamental limitation to accuracy is system noise caused either by mechanical or electrical fluctuations.

Sequential lobing, or lobe switching, was one of the first tracking-radar techniques to be employed. Early applications were in airborne-interception radar, where it provided directional information for homing on a target, and in ground-based antiaircraft fire-control radars. It is not used as often in modern tracking-radar applications as some of the other techniques to be described.

## CONICAL SCAN

A logical extension of the simultaneous lobing techniques described in the previous section is to rotate continuously an offset antenna beam rather than discontinuously step the beam between four discrete positions. This is known as conical scanning (Figure 2). The angle between the axis of rotation (which is usually, but not always, the axis of the antenna reflector) and the axis of the antenna beam is called the squint angle. Consider a target at position A. The echo signal will be modulated at a frequency equal to the rotation frequency of the beam. The amplitude of the echo-signal modulation will depend upon the shape of the antenna pattern, the squint angle, and the angle between the target line of sight and the rotation axis. The phase of the modulation depends on the angle between the target and the rotation axis. The conical-scan modulation is extracted from the echo signal and applied to a servo-control system which continually positions the antenna on the target [Note that two servos are required because the tracking problem is two-dimensional. Both the rectangular (az-el) and polar tracking coordinates may be used.] When the antenna is on target, as in B of Figure 2, the line of sight to the target and the rotation axis coincide, and the conical-scan modulation is zero.

rotates, it is called a nutating feed. A rotating feed causes the polarization to rotate. The latter type of requires a rotary joint. The nutating feed requires a flexible joint. If the antenna is small, it may be easier to rotate the dish, which is offset, rather than the feed, thus avoiding the problem of a rotary or flexible RF feed in the feed. A typical conical-scan rotation speed is 30 r/s. The same motor that provides the conical-scan rotation of the antenna beam also drives a two-phase reference generator with two outputs  $90^\circ$  apart in phase. These two outputs serve as a reference to extract the timing and azimuth errors. The received echo signal is sent to the receiver from the antenna via two rotary joints (as shown in the block diagram). One rotary joint permits motion in azimuth; the other, in elevation.

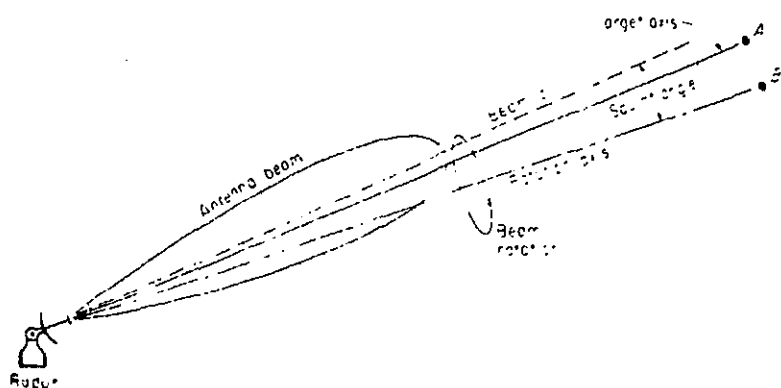


Figure 2 Conical-Scan Tracking.

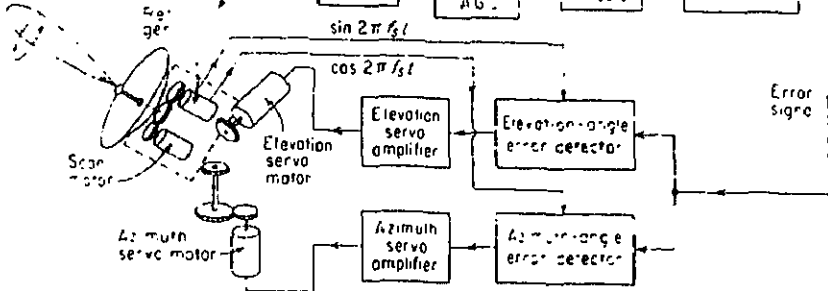


Figure 3 Block diagram of conical-scan tracking radar.

The receiver is a conventional superheterodyne except for features peculiar to the conical-scan tracking radar. One feature not found in other radar receivers is a means of extracting the conical-scan modulation, or error signal. This is accomplished after the second detector in the video portion of the receiver. The error signal is compared with the elevation and azimuth reference signals in the angle-error detectors, which are phase-sensitive detectors. A phase-sensitive detector is a nonlinear device in which the input signal (in this case the angle-error signal) is mixed with the reference signal. The input and reference signals are of the same frequency. The output d-c voltage reverses polarity as the phase of the input signal changes through 180°. The magnitude of the d-c output from the angle-error detector is proportional to the error, and the sign (polarity) is an indication of the direction of the error. The angle-error-detector outputs are amplified and drive the antenna elevation and azimuth servo motors.

The angular position of the target may be determined from the elevation and azimuth of the antenna axis. The position can be read out by means of standard angle transducers such as synchros, potentiometers, or analog-to-digital-data converters.

generator eliminates the pulse repetition frequency and reduces its harmonics. It also has the practical advantage that the magnitude of the conical-scan modulation is fixed because pulse stretching puts more of the available energy at the modulation frequency. The pulse repetition frequency must be sufficiently large compared with the conical-scan frequency for proper boxcar filtering. It may be necessary to provide additional filtering to attenuate undesired cross-modulation frequency components.

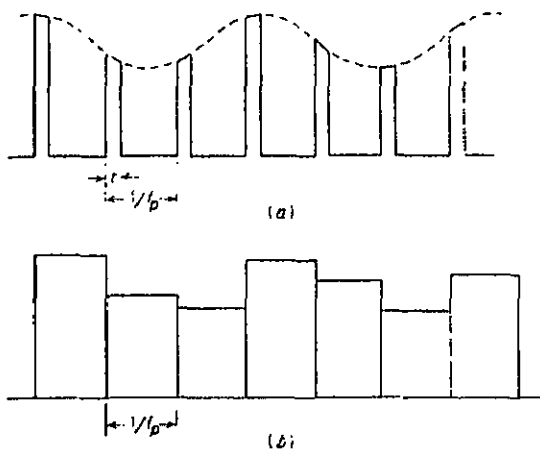


Figure 4

Other considerations. In both the sequential-lobing and conical-scan techniques, the measurement of the angle in two orthogonal coordinates (azimuth and elevation) requires that a minimum of three pulses be processed. In practice, however, the minimum number of pulses in sequential lobing is usually four--one per quadrant. Although a conical-scan radar can also be operated with only four pulses per revolution, it is more usual to have ten or more per revolution. This allows the modulation due to the angle error to be that of a continuous sine wave. Thus the prf is usually at least an order of magnitude greater than the conical-scan frequency. The scan frequency also must be at least an order of magnitude greater than the tracking bandwidth.

scan, the train of echo pulses must contain no amplitude-modulation components other than the modulation produced by scanning. If the echo pulse-train did contain additional modulation components, caused, for example, by a fluctuating target cross section, the tracking accuracy might be degraded, especially if the frequency components of the fluctuations were at or near the conical-scan frequency or the sequential-lobing rate. The effect of the fluctuating echo can be sufficiently serious in some applications to severely limit the accuracy of those tracking radars which require many pulses to be processed in extracting the error signal.

Pulse-to-pulse amplitude fluctuations of the echo signal have no effect on tracking accuracy if the angular measurement is made on the basis of one pulse rather than many. There are several methods by which angle-error information might be obtained with only a single pulse. More than one antenna beam is used simultaneously in these methods, in contrast to the conical-scan or lobe-switching tracker, which utilizes one antenna beam on a time-shared basis. The angle of arrival of the echo signal may be determined in a single-pulse system by measuring the relative phase or the relative amplitude of the echo pulse received in each beam. The names simultaneous lobing and monopulse are used to describe those tracking techniques which derive an angle-error information on the basis of a single pulse.

An example of a simultaneous-lobing technique is amplitude-comparison monopulse, or more simply, monopulse. In this technique the RF signals received from two offset antenna beams are combined so that both the sum and the difference signals are obtained simultaneously. The sum and difference signals are multiplied in a phase-sensitive detector to obtain both the magnitude and the direction of the error signal. All the information necessary to determine the angular error is obtained on the basis of a single pulse; hence the name monopulse is quite appropriate.

Amplitude-comparison monopulse. The amplitude-comparison monopulse employs two overlapping antenna patterns (Figure 5a) to obtain the angular error in one coordinate. The two overlapping antenna beams may be generated with a single reflector or with a lens antenna illuminated by two adjacent feeds. (A cluster of four feeds may be used if both elevation and azimuth-error signals are wanted.) The sum of the two antenna patterns of Figure 5a is shown in Figure 5b, and the

A block diagram of the amplitude-comparison-monopulse tracking radar for a single angular coordinate is shown in Figure 6. The two adjacent antenna feeds are connected to the two arms of a hybrid junction such as a "magic T," a "rat race," or a short-slot coupler. The sum and difference signals appear at the two other arms of the hybrid. On reception, the outputs of the sum arm and the difference arm are each heterodyned to an intermediate frequency and amplified as in any superheterodyne receiver. The transmitter is connected to the sum arm. Range information is also extracted from the sum channel. A duplexer is included in the sum arm for the protection of the receiver. The output of the phase-sensitive detector is an error signal whose magnitude is proportional to the angular error and whose sign is proportional to the direction.

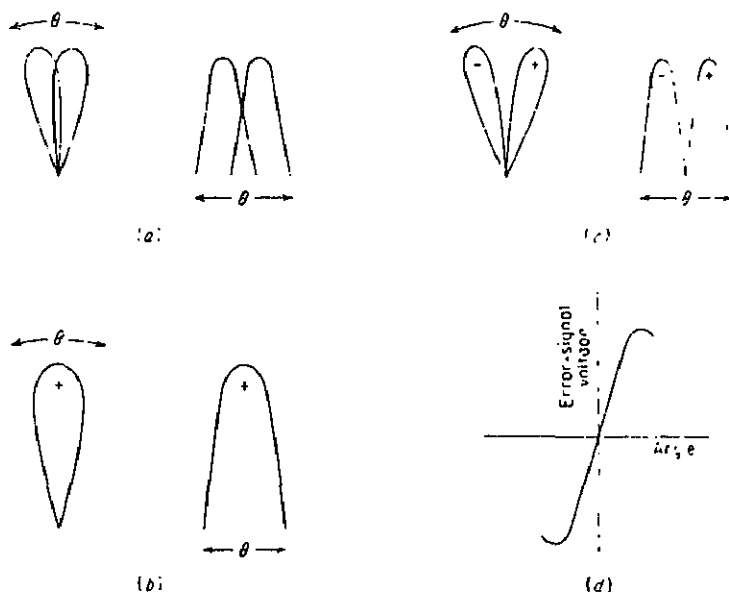
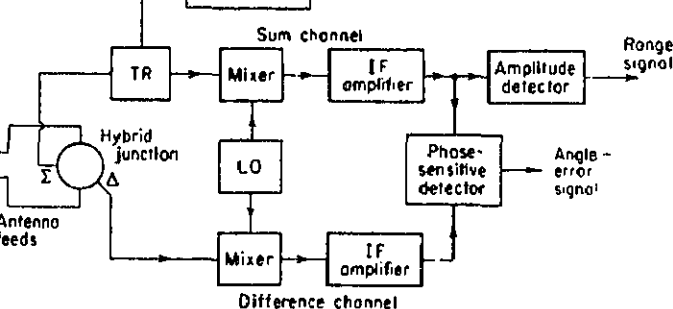


Figure 5

The output of the monopulse radar is used to perform automatic tracking. The angular-error signal actuates a servo-control system to position the antenna, and the range output from the sum channel feeds into an automatic-range-tracking unit.





Block diagram of amplitude-comparison monopulse radar (one angular coordinate).

Figure 6

signal in the IF portion of the receiver were  $A_s \cos \omega_{IF} t$ , difference signal would be either  $A_d \cos \omega_{IF} t$  or  $-A_d \cos \omega_{IF} t$  ( $A_s > 0, A_d > 0$ ), depending on which side of the target is the target. Since  $-A_d \cos \omega_{IF} t = A_d \cos \omega_{IF} (t + \pi)$ , the sign of the difference signal may be measured by determining whether the difference signal is in phase with the sum signal or 180° out of phase.

Although a phase comparison is a part of the amplitude-comparison-monopulse radar, the angular-error signal is actually derived by comparing the echo amplitudes from simultaneous offset beams. The phase relationship between signals in the offset beams is not used. The purpose of the phase-sensitive detector is to conveniently furnish the sign of the error signal.

Block diagram of a monopulse radar with provision for extracting error signals in both elevation and azimuth is shown in Figure 7. The cluster of four feeds generates four spatially overlapping antenna beams. The feeds might be fed with a parabolic reflector, Cassegrain antenna, or a feed horn. All four feeds generate the sum pattern. The difference pattern in one plane is formed by taking the sum of two adjacent feeds and subtracting this from the sum of the other two adjacent feeds. The difference pattern in the

Since a phase comparison is made between the output of the sum channel and each of the difference channels, it is important that the phase shifts introduced by each of the channels be almost identical. According to Page, the phase difference between channels must be maintained to within 25 or better for reasonably proper performance. The gains of the channels also must not differ by more than specified amounts.

An alternative approach to using three identical amplifiers in the monopulse receiver is to use but one IF channel which amplifies the sum signal and the two difference signals on time-shared basis. The sum signal is passed through the single IF amplifier followed by the two difference signals delayed in time by a suitable amount. Most of the gain and

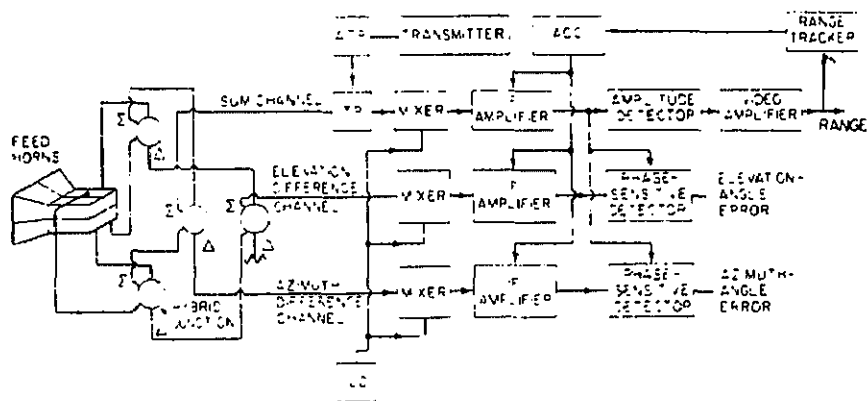


Figure 7 Block diagram of two-coordinate (azimuth and elevation) amplitude-comparison monopulse tracking radar.

gain control take place in the single IF amplifier. Any variations affect all three signals simultaneously. After amplification, compensating delays are introduced to unscramble the time sequence and bring the sum signal and the two difference signals in time coincidence. Phase detection occurs as in the conventional monopulse. Another single-channel system SCAMP converts the sum and the two difference signals to different IF frequencies and amplifies them simultaneously in a single, wide-band amplifier. The output is hard-limited to provide the effect of an instantaneous

is to ease the problem associated with maintaining identical phase and amplitude balance among the three channels of the conventional receiver. These techniques provide some advantage in this regard but they can result in undesired coupling between the azimuth and elevation channels and a loss in signal-to-noise ratio.

The monopulse antenna must generate a sum pattern with high efficiency (maximum boresight gain), and a difference pattern with a large value of slope at the crossover of the offset beams. Furthermore, the sidelobes of both the sum and the difference patterns must be low. The antenna must be capable of the desired bandwidth, and the patterns must have the desired polarization characteristics. It is not surprising that the achievement of all these properties cannot always be fully satisfied simultaneously. Antenna design is an important part of the successful realization of a good monopulse radar.

## TRACKING IN RANGE

In most tracking-radar applications the target is continuously tracked in range as well as in angle. Range tracking might be accomplished by an operator who watches an A-scope or J-scope presentation and manually positions a handwheel in order to maintain a marker over the desired target pip. The setting of the handwheel is a measure of the target range and may be converted to a voltage that is supplied to a data processor.

As target speeds increase, it is increasingly difficult for an operator to perform at the necessary levels of efficiency over a sustained period of time, and automatic tracking becomes a necessity. Indeed, there are many tracking applications where an operator has no place, as in a homing missile or in a small space vehicle.

The technique for automatically tracking in range is based on the split range gate. Two range gates are generated as shown in Figure 8. One is the early gate, and the other is the late gate. The echo pulse is shown in Figure 8a the relative position of the gates at a particular instant in Figure 8b and the error signal in Figure 8c. The portion of the signal energy contained in the early gate is less than that in the late gate. If the outputs of the two gates are subtracted, an error signal (Figure 8c) will result which

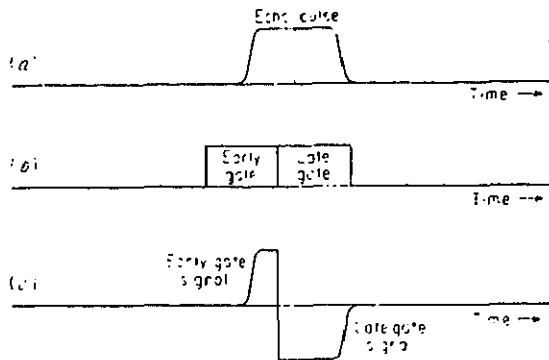


Figure 8

The range gating necessary to perform automatic track offers several advantages as by-products. It isolates target, excluding targets at other ranges. This permits boxcar generator to be employed. Also, range gating improves the signal-to-noise ratio since it eliminates the noise from the other range intervals. Hence the width of the gate should be sufficiently narrow to minimize extraneous noise. On the other hand, it must not be so narrow that an appreciable fraction of the signal energy is excluded. A reasonable compromise is to make the gate width of the order of the pulse width.

A target of finite length can cause noise in range-tracking circuits in an analogous manner to angle-fluctuation (glint) in the angle-tracking circuits. Range-tracking noise depends on the length of the target and its shape. It has been reported that the rms value of the range noise is approximately 0.8 of the target length when tracking is accomplished with a video split-range-gate error detector.

## F. ACQUISITION

A tracking radar must first find and acquire its target before it can operate as a tracker. Therefore it is necessary for the radar to scan an angular sector in the presence of the target is suspected. Most tracking radars employ a narrow pencil-beam antenna. Searching a large volume in space for an aircraft target with a narrow

radar, developed during world war II for the aiming of antiaircraft-gun batteries. The SCR-584 antenna was rotated at the rate of 6rpm and covered a  $20^\circ$  elevation angle in 1 min. The Palmer scan derives its name from the familiar penmanship exercises of grammar school days. It consists of a rapid circular scan (conical scan) about the axis of the antenna, combined with a linear movement of the axis of rotation. When the axis of rotation is held stationary, the Palmer scan reduces to the conical scan. Because of this

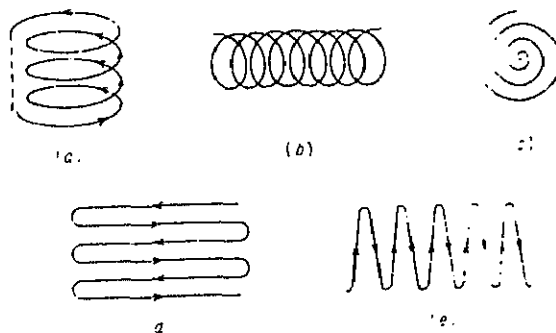


Figure 9

property, the Palmer scan is sometimes used with conical-scan tracking radars which must operate with a search as well as a track mode since the same mechanisms used to produce conical scanning can also be used for Palmer scanning. Some conical-scan tracking radars increase the squint angle during search in order to reduce the time required to scan a given volume. The conical scan of the SCR-584 was operated during the search mode and was actually a Palmer scan in a helix. In general, conical scan is performed during the search mode of most tracking radars.

The Palmer scan is suited to a search area which is larger in one deminsion than another. The spiral scan covers an angular search volume with circular symmetry. Both the spiral scan and the Palmer scan suffer from the disadvantage that all parts of the scan volume do not receive the same

raster scan--nodding scan many also be used to obtain spherical coverage, that is, elevation angle extending to  $90^\circ$  and the azimuth scan angle to  $360^\circ$ .

The helical scan and the nodding scan can both obtain hemispheric coverage with a pencil beam. The nodding scan is also used with height-finding radars. The helical, spiral, and raster scans are employed in fire-control tracking radars to assist in the acquisition of targets when the search sector is of limited extent.

Tracking in doppler. Tracking radars that are based on pulse-doppler, or MTI principles can also track moving targets by frequency shift generated by a moving target. This is accomplished with a frequency discriminator and a phase-locked oscillator to maintain the received signal in tune with a narrow-band filter. It is also possible to use a phase-locked loop, or phase-sensitive discriminator which drives a voltage-controlled oscillator to hold in tune step with the input signal. Tracking the doppler shift with the equivalent of a narrow-band filter allows enough resolution to encompass the frequency spectrum of the target signal allows an improvement in the signal-to-noise ratio compared with wideband processing. It can also improve the resolution of the desired moving target from stationary clutter. The doppler tracking filter is sometimes called a speed gate.

## G. COMPARISON OF TRACKERS

Of the four continuous-tracking-radar techniques that have been discussed (sequential lobing, conical scan, amplitude-comparison monopulse, and phase-comparison monopulse), the conical scan and amplitude-comparison monopulse have found more application than the other two. The phase-comparison monopulse has not been too popular because of the awkwardness of its antenna (four separate antennas) and the fact that to point their individual beams in the same direction because the sidelobe levels might be higher than the main lobe. Although sequential lobing is similar to conical scan, the latter is preferred in most applications, since it has less loss and the antenna and feed systems are simpler. In this section, only the conical-scan and the amplitude-comparison monopulse will be compared. The latter will be referred to simply as monopulse.

The tracking accuracy of a monopulse radar is superior to that of the conical-scan radar because of the absence of target amplitude-fluctuations and because of its greater signal-to-noise ratio. It is the preferred technique for precision tracking. However, both monopulse and conical-scan radars are degraded equally by the wandering of the apparent position of the target (glint).

The monopulse radar is the more complex of the two. Three separate receivers are necessary to derive the error signal in two orthogonal angular coordinates. Only one receiver is needed in the conical-scan radar. (There are certain monopulse implementations that can use either one or two receivers, but at some sacrifice in performance.) Since the monopulse radar compares the amplitudes of signals received in three separate channels, it is important that the gain and phase shift through these channels be identical. The R circuitry that generates the sum and difference signals in monopulse radar has been steadily improved, and can be realized without excessive physical bulk. A popular form of antenna for monopulse is the Cassegrain.

With the monopulse tracker it is possible to obtain a measure of the angular error in two coordinates on the basis of a single pulse. A minimum of four pulses are usually necessary with the conical-scan radar. However, a continuous-tracking radar seldom makes a measurement on a single pulse. (Phase array radars and some surveillance radars, however, might use the monopulse principle to extract an angle measurement on the basis of a single pulse.) In practice, the two radars utilize essentially the same number of pulses to obtain an error signal if the servo tracking bandwidths and pulse repetition frequencies are the same. The monopulse radar first makes its angle measurement and then integrates a number of pulses to obtain the required signal-to-noise ratio and to smooth the error. The conical-scan radar, on the other hand, integrates a number of pulses first and then extracts the angle measurement.

Because a monopulse radar is not degraded by amplitude fluctuations, it is less susceptible to hostile electronic countermeasures than is conical scan.

In brief, the monopulse radar is the better tracking technique; but in many applications where the ultimate in performance is not needed, the conical-scan radar is used because it is less costly and less complex.

One method of obtaining tracks with a surveillance radar is to have an operator manually mark with grease pencil on the face of the cathode-ray tube the location of the target at each scan. The simplicity of such a procedure is offset by the poor accuracy of the track. The accuracy of track can be improved by using a computer to determine the trajectory from inputs supplied by an operator. A human operator, however, cannot update target tracks at a rate greater than about once per two seconds. Thus, a single operator can handle more than about six target tracks when the radar has a twelve-second scan rate (5 rpm antenna rotation rate). Furthermore an operator's effectiveness in detecting targets decreases rapidly after about a half hour of continuous operation. The radar operator's traffic handling limitations and the effects of fatigue can be mitigated by automating the target detection and tracking process with data processing called automatic detection and tracking (ADT). The availability of digital data processing technology has made ADT economically feasible. An ADT system performs the functions of target detection, track initiation, track association, track update, track smoothing (filtering) and track termination.

The automatic detector part of the ADT quantizes the range into intervals equal to the range resolution. At each range interval the detector integrates "n" pulses, where "n" is the number of pulses expected to be returned from a target as the antenna scans past. The integrated pulses are compared with a threshold to indicate the presence or absence of a target. An example is the commonly used moving window detector which examines continuously the last "n" samples within each quantized range interval and announces the presence of a target if "m" out of "n" of these samples cross a preset threshold. By locating the center of the integrated pulses, an estimate of the target's angular direction is obtained. This is called beam splitting.

If there is but one target present within the radar's coverage, then detections on two scans are all that is needed to establish a target track and to estimate its velocity. However, there are usually other targets present, as clutter echoes present, so that three or more detections are needed to reliably establish a track without the possibility of false or spurious tracks. Although a computer can be programmed to recognize and reject false tracks, a large number of false tracks can overload the computer and result in



characteristic, such as its altitude, might also prove of help when performing track association. Thus, the quality of the ADT will depend significantly on the ability of the radar to reject unwanted signals.

When a new detection is received, an attempt is made to associate it with existing tracks. This is aided by establishing for each track a small search region, or gate, within which a new detection is predicted based on the estimate of the target speed and direction. It is desired to make the gate as small as possible so as to avoid having more than one echo fall within it when the traffic density is high or when two tracks are close to one another. However, a large gate area is required if the tracker is to follow target turns or maneuvers. More than one size gate might therefore be used to overcome this dilemma. The size of the small gate would be determined by the accuracy of the track. When a target does not appear in the small gate, a larger gate would be used whose search area is determined by the maximum acceleration expected of the target during turns.

On the basis of the past detections the track-while-scan radar must make a smoothed estimate of a target's present position and velocity, as well as a predicted position and velocity. One method for computing this information is the so-called  $\alpha$ - $\beta$  tracker (also called the g-h tracker), which

computes the present smoothed target position  $\bar{x}_n$  and velocity  $\bar{x}$  by the following equations

$$\text{Smoothed position: } \bar{x}_n = x_{pn} + \alpha(x_n - x_{pn})$$

$$\text{Smoothed velocity: } \bar{x}_n = \bar{x}_{n-1} + \frac{\beta}{T_s}(x_n - x_{pn})$$

where  $x_{pn}$  = predicted position of the target at the nth scan,  $x_n$  = measured position at the nth scan,  $\alpha$  = position smoothing parameter,  $\beta$  = velocity smoothing parameter, and  $T_s$  = time between observations. The predicted position at the  $n + 1$ st scan is  $\bar{x}_n + \bar{x}_n T_s$ . (When acceleration is important a third equation can be added to describe an  $\alpha$ - $\beta$ - $\gamma$  tracker, where  $\gamma$  = acceleration smoothing parameter.) For  $\alpha = \beta = 0$ , the tracker uses no current information, on

rapid response to maneuvering targets (requiring width). Another criterion for selecting the  $\alpha$ - $\beta$  coefficients is based on the best linear track fitted to radar data in a least squares sense. This gives the of  $\alpha$  and  $\beta$  as

$$\alpha = \frac{2(2n - 1)}{n(n + 1)} \quad \beta = \frac{6}{n(n + 1)}$$

where  $n$  is the number of the scan or target observation ( $n > 2$ ).

The standard  $\alpha$ - $\beta$  tracker does not handle the maneuvering target. However, an adaptive  $\alpha$ - $\beta$  tracker is one which varies the two smoothing parameters to achieve a variable bandwidth so as to follow maneuvers. The value of  $\alpha$  is set by observing the measurement error  $x_n - x_{pn}$ . At the start of tracking the bandwidth is made wide and then narrows down if the target moves in a straight-line trajectory. As the target maneuvers or turns, the bandwidth is widened to keep the tracking error small.

The Kalman filter is similar to the classical  $\alpha$ - $\beta$  tracker except that it inherently provides for the dynamical maneuvering target. In the Kalman filter a model for the measurement error has to be assumed, as well as a model for the target trajectory and the disturbance or uncertainty in the trajectory. Such disturbances in the trajectory may be due to neglect of higher-order derivatives in the model of the dynamics, random motions due to atmospheric turbulence and deliberate target maneuvers. The Kalman filter, in principle, utilizes a wide variety of models for measurement noise and trajectory disturbance; however, it is often assumed that these are described by white noise with zero mean. A maneuvering target does not always fit such an ideal model, since it is quite likely to produce correlated observations. The proper inclusion of realistic dynamical models increases the complexity of the calculations and it is difficult to describe a priori the precise nature of the trajectory disturbances. Some form of adaptation or learning maneuver is required. The Kalman filter is sophisticated and accurate, but is more costly to implement than several other methods commonly used for the smoothing and prediction of tracking data. Its chief advantage is

and  $\beta$  accordingly. In some radar systems, the data rate might also be increased during target maneuvers. As the means for choosing  $\alpha$  and  $\beta$  become more sophisticated, the optimal  $\alpha$ - $\beta$  tracker becomes equivalent to a Kalman filter even for a target trajectory model with error. In this sense, the optimal  $\alpha$ - $\beta$  tracking filter is one in which the values of  $\alpha$  and  $\beta$  require knowledge of the statistics of the measurement errors and the prediction errors, and in which  $\alpha$  and  $\beta$  are determined in a recursive manner in that they depend on previous estimates of the mean square error in the smoothed position and velocity.

The above discussion has been in terms of a sampled-data system tracking targets detected by a surveillance radar. The concept of the  $\alpha$ - $\beta$  tracker or the Kalman filter also can be applied to a continuous, single-target tracking radar when the error signal is processed digitally rather than analog. Indeed, the equations describing the  $\alpha$ - $\beta$  tracker are equivalent to the type II servo system widely used to model the continuous tracker.)

If for some reason, the track-while-scan radar does not receive target information on a particular scan, the smoothing and prediction operation can be continued by properly accounting for the missed data. However, when data to update a track is missing for a sufficient number of consecutive scans the track is terminated. Although the criterion for terminating a track depends on the application, one example suggests that when three target reports are used to establish a track, five consecutive misses is a suitable criterion for termination.

One of the corollary advantages of ADT is that it effects a bandwidth reduction in the output of a radar so as to allow the radar data to be transmitted to another location via narrowband phone lines rather than wideband microwave links. This makes it more convenient to operate the radar at a remote site, and permits the outputs from many radars to be communicated economically to a central control point.

It should be noted that the adaptive thresholding of the automatic detector can cause a worsening of the range-resolution. By analogy to the angular resolution possible in the angle coordinate it would seem a priori that two targets might be resolved in range if the separation is about 0.8 o

3. What controls the phase and time relationships of the frequencies as they exit the LIFMOP filter?
4. What is the meaning of a "time domain?"
5. What is the meaning of a "frequency domain?"

What would be the bandwidth generated by applying a .5 usec pulse to a COMO?

- a. 20MHz
- b. 2MHz
- c. 40MHz
- d. 4MHz

A typical bandpass for the tuned amplifiers in each channel of the matched filter is:

- a. 1 MHz
- b. .5 MHz
- c. 10 MHz
- d. 5 MHz

List three advantages of pulse compression radar over conventional radars?

What contributes to the high resolution capabilities of the chirp radar?

- 11.9.1 Given statements concerning the difference between radar echoes from fixed and moving targets, select the correct statement(s).
- 11.9.2 Given a block diagram of a delay line canceler list of statements, match the correct statements with the appropriate block.
- 11.9.3 Given statements concerning the operating principle of a noncoherent MTI radar, select the correct statements.
- 11.9.4 Given statements concerning the operating principle of a coherent MTI radar, select the correct statements.
- 11.9.5 Given statements concerning blind speeds in MTI radar, select the correct statements.
- 11.9.6 Given statements concerning relative advantages/disadvantages of coherent and noncoherent MTI select the correct statements.

#### STUDY ASSIGNMENT:

- Read:     1. Aviation Electronics Technician 1 and NAVTRA 10318-D, Chapter 8, pp 226-228.  
          2. Information Sheet No. 11.9.11 "MOVING TARGET INDICATOR RADAR".
- Complete: Student Activity Guide 11.9.1S

STUDY QUESTIONS: None

- b. Display moving targets as a line of video on the display.
  - c. Display moving targets only.
  - d. Display moving and stationary targets.
2. What is the purpose of the Coho?
- a. Internal reference
  - b. External reference
  - c. Pulsing oscillator
  - d. To discriminate between stationary and moving targets.
3. What is the external reference for the noncoherent radar?
- a. Coho
  - b. Como
  - c. Moving targets
  - d. Stationary targets
4. What is the purpose of the delay line canceler?
- a. To cancel the effects of the delay line.
  - b. To cancel moving targets
  - c. To cancel stationary targets
  - d. To repeat several times and keep the image on the screen.

- c. Phases of each channel must be matched.
  - d. Phases of each channel must be mismatched.
6. Which of the following could be used to delay t in the delay channel of the delay line canceler
- a. Magnetostrictive
  - b. Quartz
  - c. Mercury
  - d. PFN
7. At what velocities do blind speeds occur?
- a. 100 Kts
  - b.. 500 Kts
  - c. PRF of the radar
  - d. When the velocity of the target produces a shift equal to or a multiple of the PRF of radar.



radar systems. They must have the capabilities of locating the enemy in all kinds of weather, day or night. Because of the speeds that newer aircraft are traveling, both friend and foe, the radar system must give accurate range resolution, and in some cases, whether or not the target is moving and the direction it is moving. No longer can the radar operator be solely depended upon to distinguish moving objects.

Today, there are radar systems of this nature already in operation in the fleet, both in attack aircraft (A6A Intruder) and long range, early warning aircraft (E2A, Hawkeye). Radar systems that have these capabilities are known as moving target indicator (MTI) and airborne moving target indicator (AMTI).

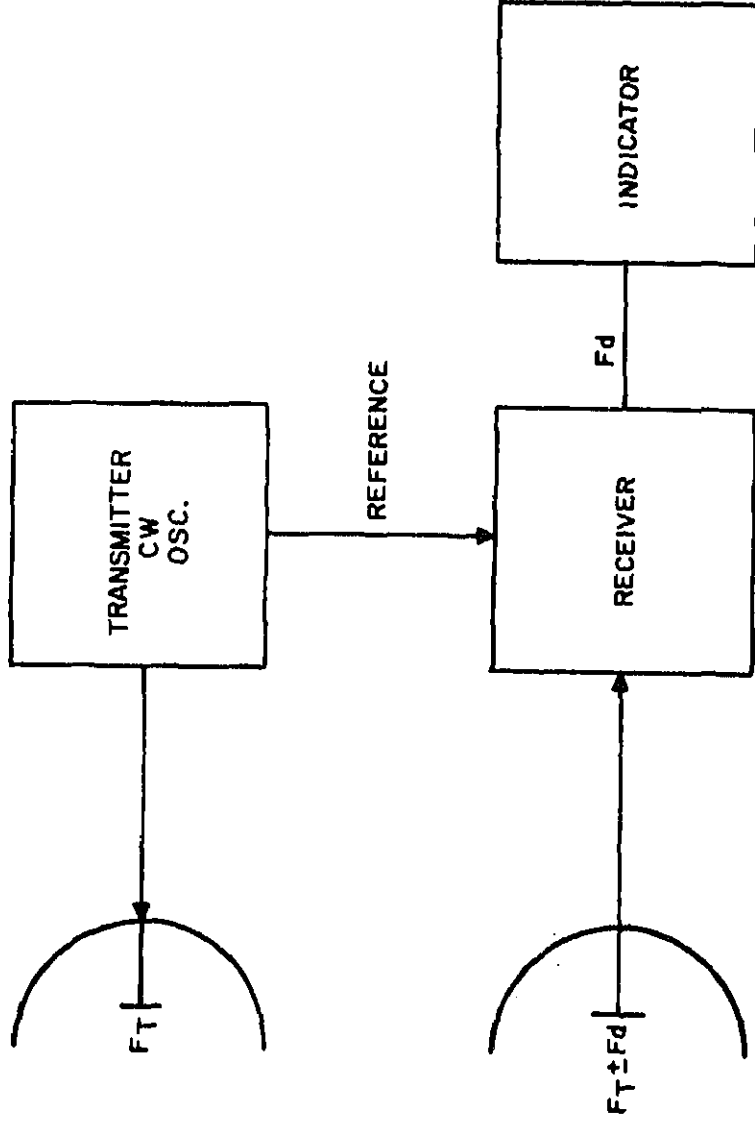
REFERENCES: Introduction to Radar Systems, SKOLNIK, McGraw Hill, 1980, Chapter 4.

## FORMATION

### HERENT SYSTEMS

The Doppler shift in frequency caused by a moving target may be used in pulse radar to distinguish fixed from moving targets. The fixed targets are called clutter because they tend to clutter the CRT of conventional radars. The AMTI can extract the moving target echo from the clutter echo even if the clutter echo is 20 to 30 db greater than the moving echo.

Figure 1 is a simple c-w radar block diagram. The c-w oscillator serves as the transmitter and as the reference signal source. A moving target would cause the transmitted frequency ( $f_t$ ) to have an up or down  $d_s$ ; therefore the received frequency would be  $E_T \pm F_d$ . The receiver compares the return frequency with the reference frequency. The  $F_{ds}$  would then be detected and sent to the indicator. No  $F_d$  would be detected from a fixed target; thus, only moving targets would be seen on the CRT. This simple system has the disadvantage of not providing range information.



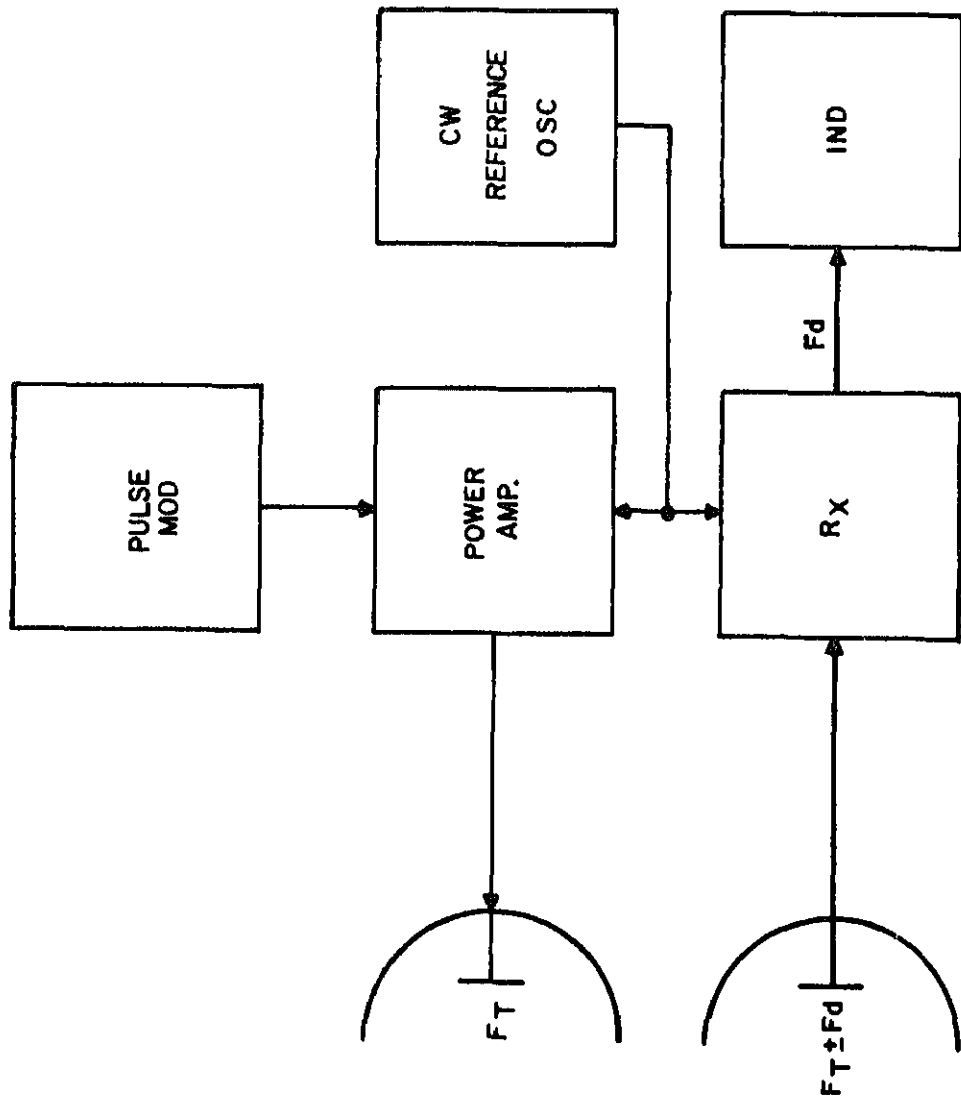
BLOCK DIAGRAM OF A BASIC DOPPLER MTI

In the coherent MTI, there has to be a definite phase relationship between the transmitted signal and the reference oscillator. The reference oscillator will be a coherent c-w oscillator, normally abbreviated COHO. Since the COHO and transmitter frequency must have a definite phase relationship, the phase of the COHO is locked to the phase of the transmitted pulse each time the transmitter fires.

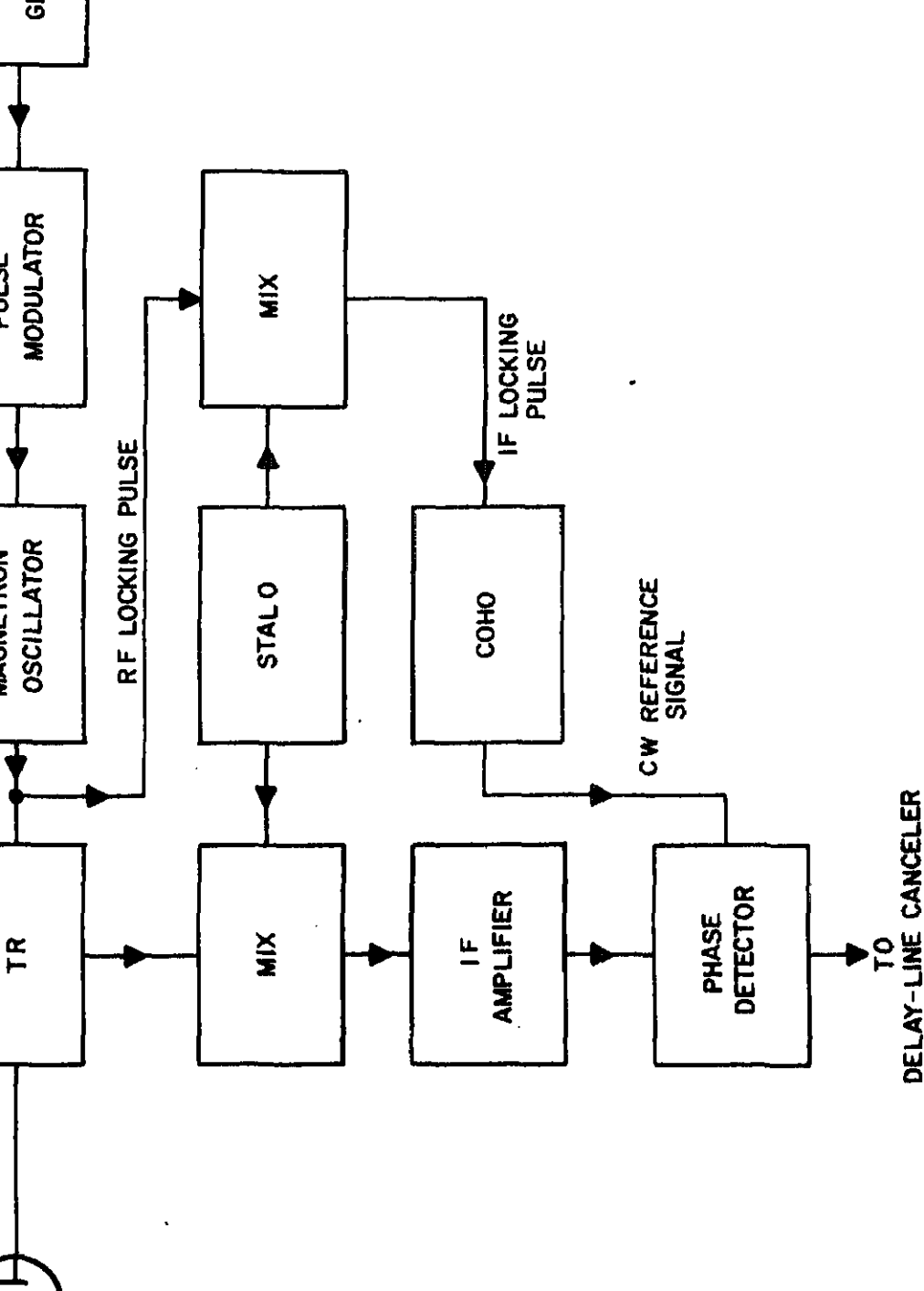
Figure 3 shows a block diagram of a coherent AMTI system. The transmitted r-f pulse is fed to the antenna for transmission and also is fed to a mixer where it is mixed with the local oscillator. The local oscillator must be very stable so a stable local oscillator (STALO) is used to provide the frequency translation needed. The output of the mixer is the i-f locking pulse that is used to lock the phase of the COHO to the transmitter. As can be seen, the COHO operates at the i-f frequency. The output from the COHO is then fed to the phase shifter. The other input to the phase shifter is from a servo which receives inputs for A/C velocity and antenna azimuth. The phase shifter provides the reference for detection of the moving target's return.

The received signal goes through the mixer, i-f amplifier and then to the phase detector. The phase detector detects any phase difference between the received frequency and the COHO. The voltage from the phase detector is fed to the delay line canceler (delay line cancelers will be covered later in this information sheet).

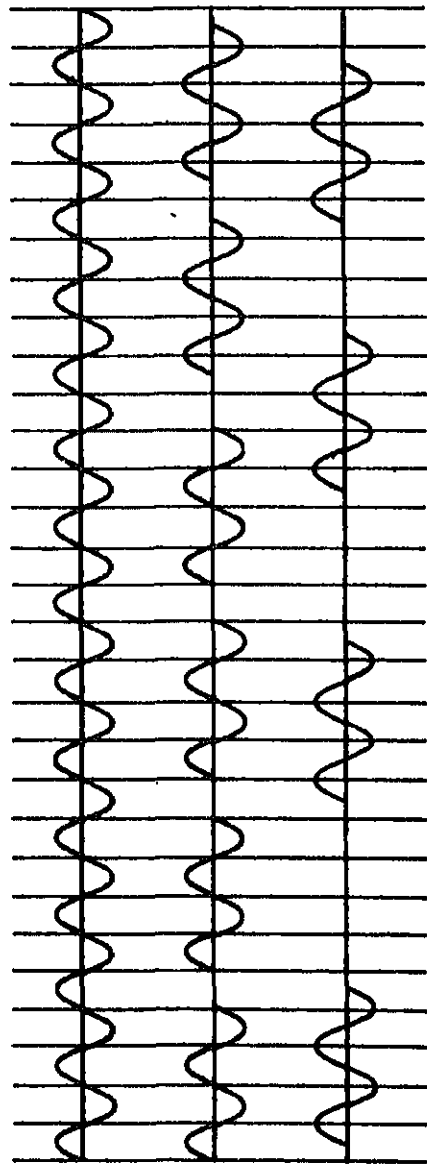
To understand what causes the phase difference between the received signal and the COHO we must look at what happens during the time of transmit and reception of the signal. (Refer to figure 4.) The transmitted pulse will return to the receiver with the same phase as it was when transmitted. The COHO is operated c-w so its phase may or may not be the same as the received signal. The transmitted pulse returns at  $T_0 + \text{Range}$ ; if it was negative going at  $T_0$  it will return with that same phase and be compared to the phase of the COHO at that time. If the target is stationary or if the target moves a



BLOCK DIAGRAM OF A PULSED-DOPPLER MTI



BLOCK DIAGRAM OF MTI RADAR WITH POWER OSCILLATOR TRANSMITTER



COHO

RETURNS FROM  
MOVING TARGET

RETURNS FROM  
STATIONARY  
BLIND SPEED

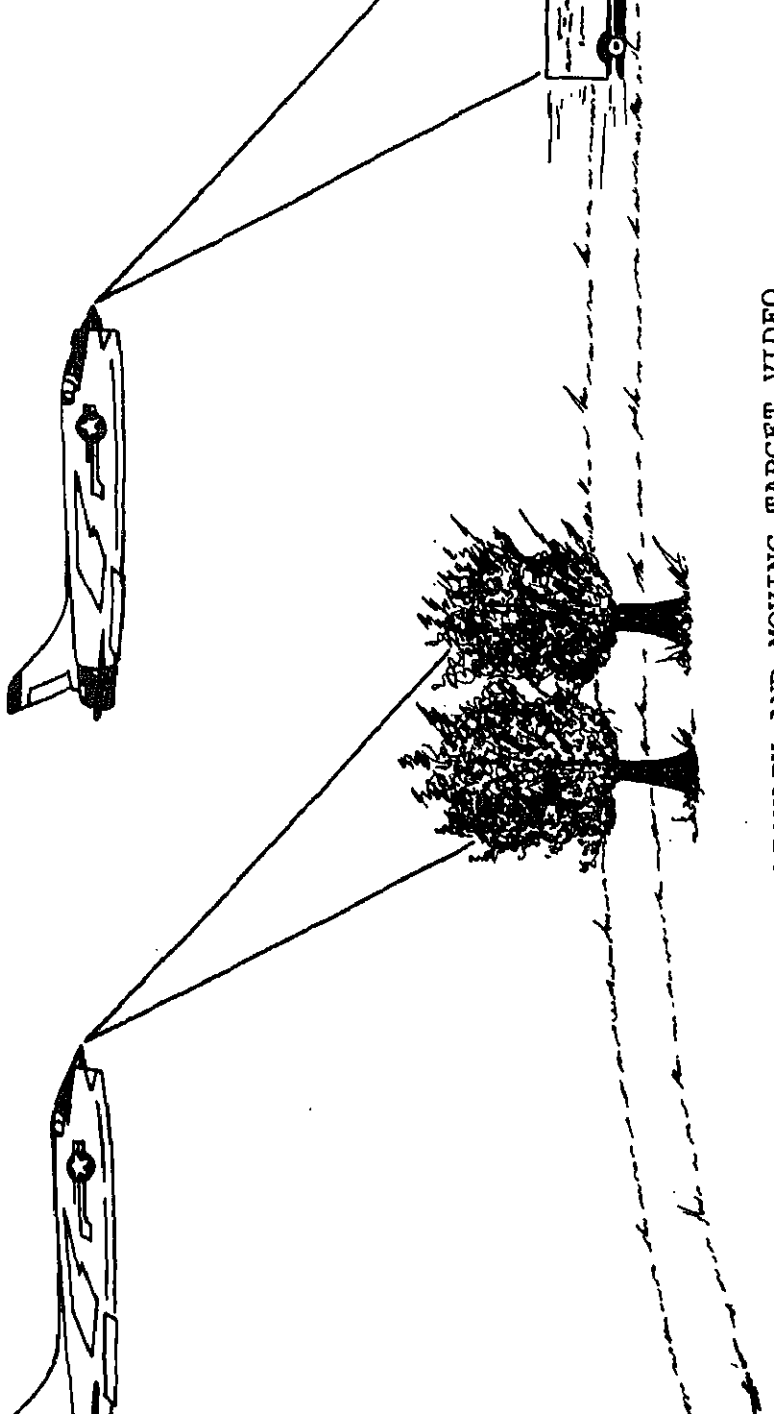
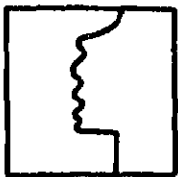
This varying phase causes a varying voltage out of the phase detector and would not be canceled in the delay line canceler.

## NONCOHERENT MTI

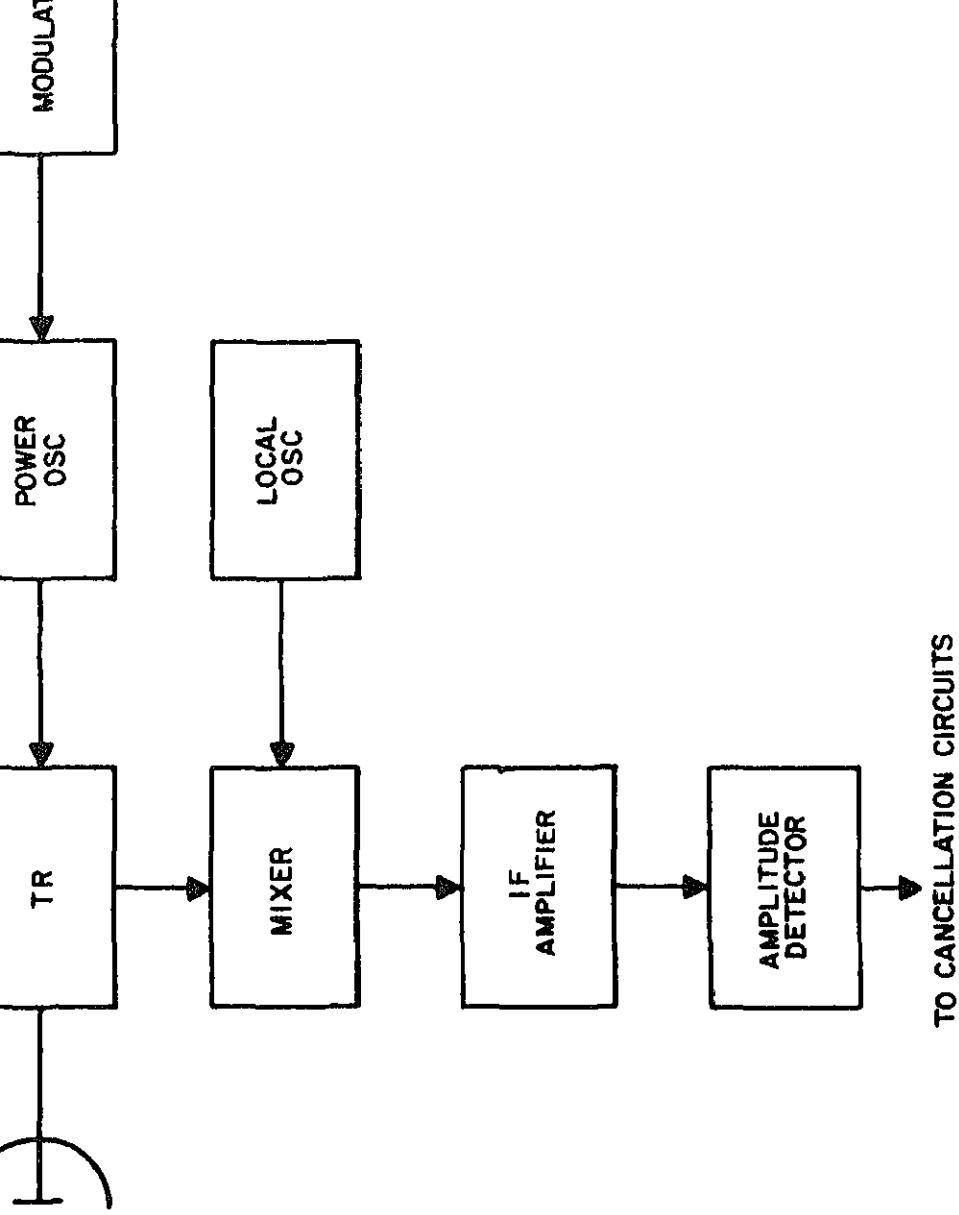
- A. The composite echo signal from a moving target and clutter fluctuates in both phase and amplitude. (Refer to figure 5.) The coherent MTI and the Doppler radar make use of the phase fluctuations.
- B. It is also possible to use the amplitude fluctuations recognize the Doppler component produced by a moving target. MTI radar that uses this principle is called noncoherent or externally coherent MTI. (Refer to figure 6.) The noncoherent MTI radar does not need an internal coherent oscillator. Amplitude limiting cannot be employed in the noncoherent MTI radar, because the desired amplitude fluctuations would be lost. Therefore, the i-f amplifier must be linear, or if a large dynamic range is required, it can be logarithmic.
- C. The detector following the i-f amplifier is a conventional amplitude detector. The local oscillator of the noncoherent radar does not have to be as frequency-stable as the coherent MTI. The output of the amplitude detector is fed to a delay line canceler.

## DELAY LINE CANCELERS

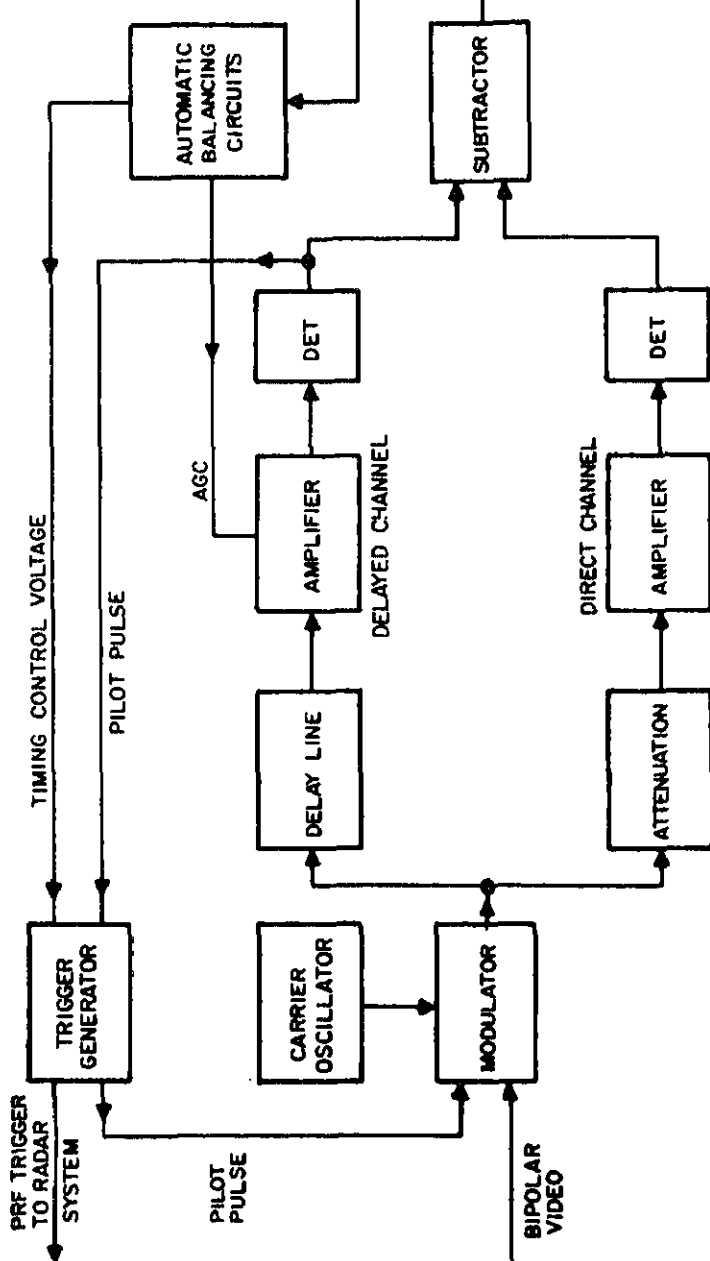
- A. The a-m delay line canceler and the f-m delay line cancelers are the two types of cancelers in use.
- B. (Refer to figure 7.) The bipolar video from the phase detector is fed to an a-m modulator where it modulates carrier frequency. The modulated output carrier goes through a delay line where it is delayed one prt; it also goes through the direct channel to a detector and then to a subtracter. The modulated carrier is subtracted from the modulated carrier caused by the previous prt. If the target represented where a moving target the bipolar inputs would vary from prt to prt; in this case, the subtracter would have an output which would be sent through a full-wave rectifier to the video circuits. If the target appeared stationary, the bipolar output of the phase detectors would not vary; therefore, both input to the subtracter would be equal resulting in no output.







BLOCK DIAGRAM OF BASIC NON-COHERENT MTI

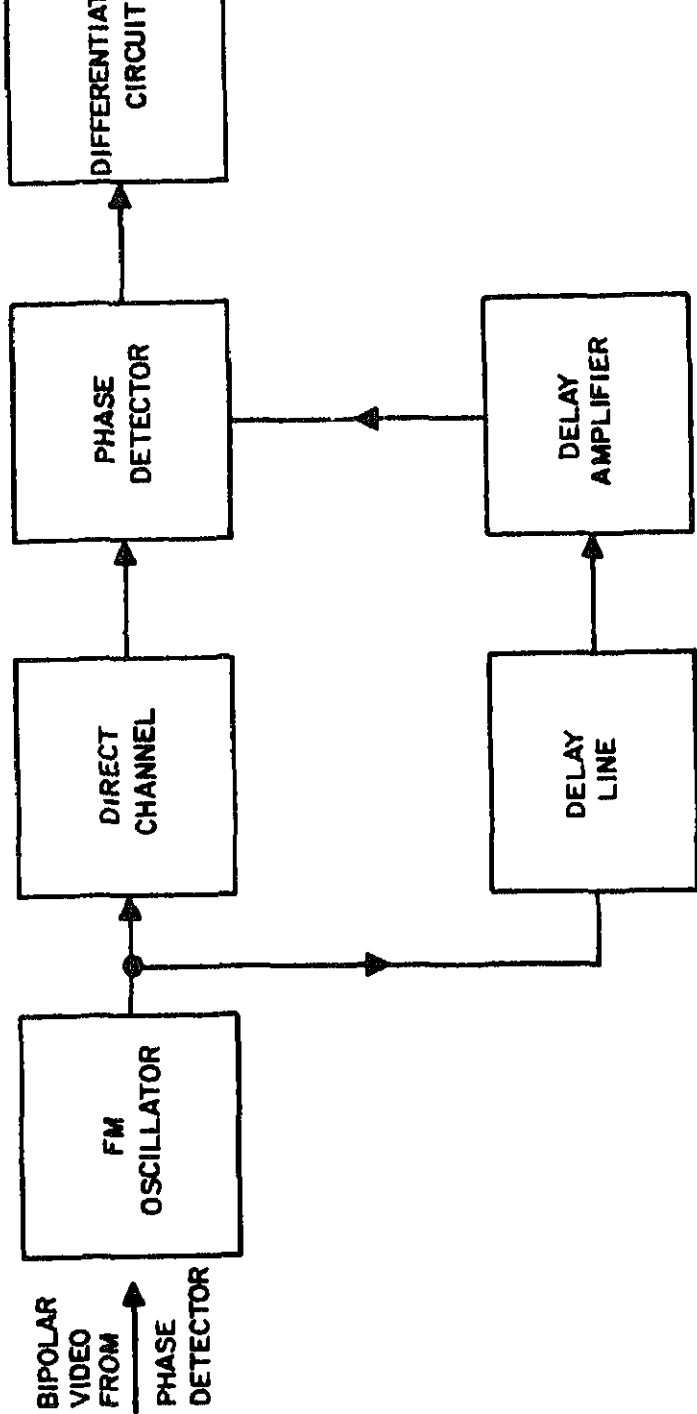


tionary target. With a stationary target fed into a canceler the output should be zero. If there is an input while these trigger pulses come into the subtracter output causes the automatic balancing circuits to vary the age to balance the two channels.

f-m delay line canceler (refer to figure 8) is not plagued with the aforementioned complications. The polar video is fed to an f-m modulator where it frequency modulates a carrier. The f-m signal takes the direct route to the phase detector where it is compared with the previous signal; the f-m signal also goes to the delayed channel where it is delayed and will be compared with the next incoming signal.

delays required in each of the delay line cancelers are usually in the milliseconds; therefore, magnetostrictive delay lines cannot be used. The delay line will be an acoustical delay line. The most commonly used are quartz and mercury delay lines.

PEEDS - In MTI when the target is traveling at a velocity that causes a Doppler shift equal to or a multiple of the prf of the radar set the target appears stationary and is not seen by the MTI radar.



- 1 Given statements concerning the antenna pattern, scanning method and information provided when using a sector PPI, select the correct statement(s).
- 2 Given statements concerning the antenna pattern, scanning method and information provided when using E-scan, select the correct statement(s).
- 3 Given statements concerning the antenna pattern, scanning method and information provided when using ADI, select the correct statement(s).
- 4 Given statements concerning the characteristics of the terrains affect on the received video in a phase scanning terrain avoidance system, select the correct statement(s).
- 5 Given statements concerning the antenna pattern, scanning method and display useable in the terrain avoidance mode, select the correct statement(s).
- 6 Given statements concerning the antenna pattern, scanning method and display useable in the terrain clearance mode, select the correct statement(s).
- 7 Given statements concerning the antenna pattern, scanning method and display useable in the terrain following mode, select the correct statement(s).
- 8 Given statements concerning the purpose of terrain avoidance radar, select the correct statement(s).

#### ASSIGNMENT:

Read: Information Sheet 11.10.1I

Complete: Student Activity Guide 11.10.1S

QUESTIONS: NONE

- c. HSD
  - d. VDI
2. What information is provided by E-scan?
- a. Range only
  - b. Range and altitude
  - c. Altitude only
  - d. None of the above
3. The ADI is part of what system?
- a. VDIG
  - b. S-scan
  - c. Sector PPI
  - d. HSD
4. What type of antenna system can provide the ADI display?
- a. Phased array
  - b. Pencil beam system
  - c. Fan beam system with the pencil beam
  - d. All of the above
5. Which of the following provides for level flight above terrain?
- a. Terrain avoidance
  - b. Terrain clearance
  - c. Terrain following
  - d. All of the above

rrain avoidance

rrain clearance

rrain following

l of the above

of the following provides for nearly constant radar  
de above the terrain?

rrain avoidance

rrain clearance

rrain following

l of the above

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terrain features such as mountains and valleys can cause problems when the flight path crosses them especially at night or in inclement weather.

The terrain avoidance radar, sometimes called terrain clearance or terrain following radar, can provide to the aircraft displays an all weather view of the area in front of the aircraft.

ces:

NA-01-85ADA-1 NATOPS Flight Manual A6E

NA-01-85ADF-2-17 Radar Set  
APQ-156 Principles of Operation

1. Contact analog display

a. Horizon line

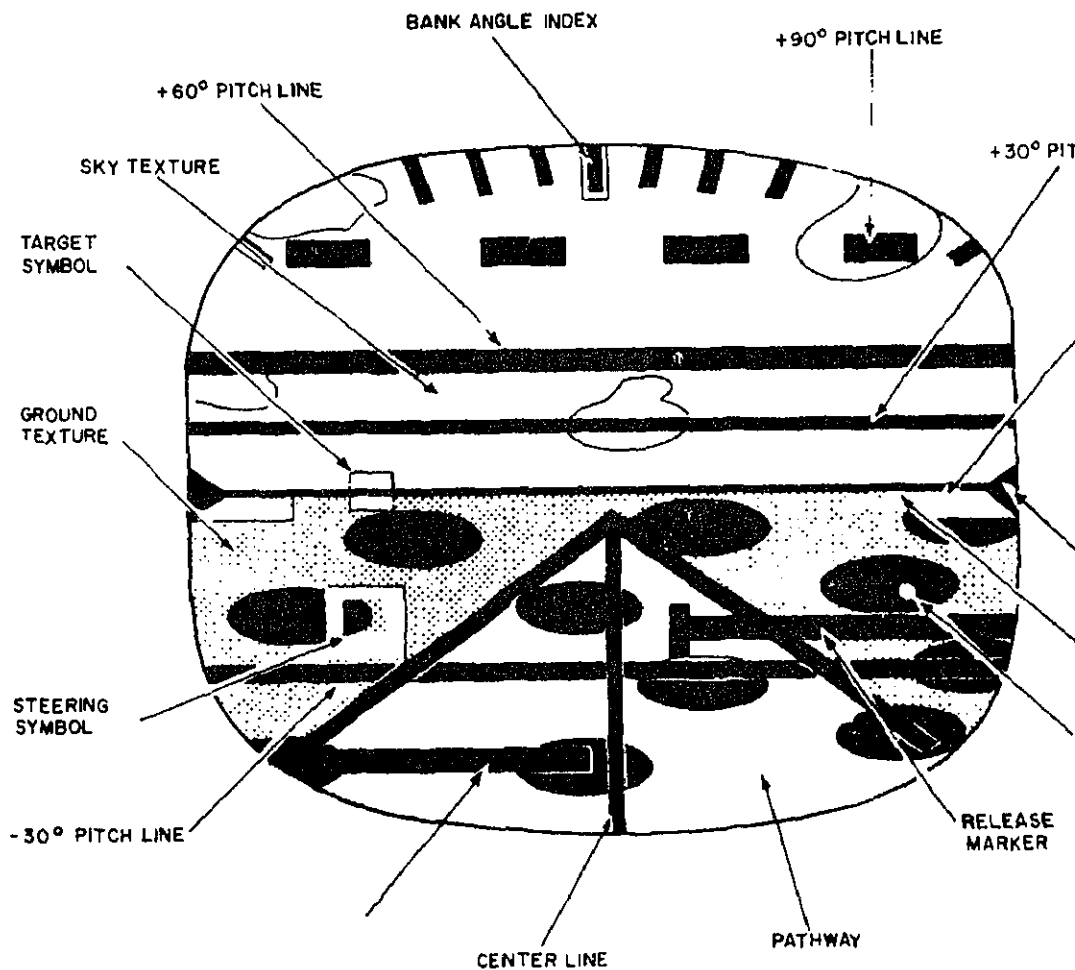
- (1) Is a line that separates ground and sky
- (2) Is controlled by the INS (ASN-92) such that it depicts pitch and roll motion and compares it to the fixed markers on the side of the instrument

b. Ground texture

- (1) Defines a ground plane readily distinguishable from the sky texture and consists of random ground texture elements.
- (2) Is controlled by the INS to depict heading changes to the pilot

c. Sky texture

- (1) Provides an additional real world reference in conjunction with the ground texture and consists of random cloud symbols.
- (2) Is also controlled by the INS to depict heading changes.



CONTACT ANALOG TEST DISPLAY  
FIGURE 1

- (3) The base of the path widens to indicate command altitude.
- (4) In addition, when the aircraft is flying on a correct heading but parallel to the path, the base of the path moves either left or right to indicate this condition.
- (5) If an attack pull-up maneuver is in progress, the path apex assumes a pulled-up position.
- (6) All information necessary for motion picture flight path comes from the ASQ-115 Motion Picture Computer.

e. Centerline

- (1) The centerline symbol is a dark line that bisects the center of the path, and indicates the center of the path.
- (2) The centerline is visible only when command heading lines are not visible. It is in the perspective center regardless of motion.

f. Command heading lines

- (1) Is composed of dark lines that are always parallel the centerline.
- (2) Three lines are always visible.
- (3) If a steering error exists, the command heading lines rotate clockwise or counter-clockwise around the path apex depending on the direction of steering error.

- (2) The lines are manually positioned by the pilot with the PITCH TRIM control on the PCB so that the markers are coincident with the horizon line with the aircraft at a particular angle of attack, so that he can return to this attitude after completing his maneuver.
- (3) The cursors are also positioned by roll information from the INS to maintain the proper perspective when the aircraft rolls.
- (4) The roll cursor is a single 3/4" white line extending down from the top perpendicular to the horizon line.
- (5) Aircraft roll can be measured by comparing the cursor with the top fiducial markers which are spaced 10° apart and the farthest markers at 60°.

h. Impact point

- (1) Consists of a bright circle that indicates the point where the aircraft would impact if it were to continue in its present attitude.
- (2) When the angle of attack approaches a stall condition, the impact point blinks on and off at a rate of two times per second to indicate to the pilot that a recovery maneuver is in order.
- (3) The blinking will also occur when the aircraft cannot pull the "G's" selected by the B/N on the computer.

- (2) When a pitch line is at the vertical center of the display, the aircraft pitch angle is equal to the pitch line degree assignment.
- (3) Since the total elevation angle of the display is 30 degrees, and the pitch lines have 30 degree separation, no more than two pitch lines can appear simultaneously on the display.
- (4) The distinction of recognizing one pitch line from the other is the physical characteristics of the pitch lines.
- (a) The +30 and -30 degree pitch lines are physically identical, however they can readily be distinguished by noting the background texture.
- (b) With the aircraft at -30 degrees pitch, the background texture consists entirely of ground texture and with +30 degree pitch, the background consists entirely of sky texture.
- (c) The +60 degree pitch line is considerably thicker than the 30 degree pitch line and the +90° pitch line consists of a series of dashes.
- (d) Consequently the +60 and +90 degree pitch lines are readily distinguished from the other pitch lines.

j. Pull-up marker

- (1) Is a solid black bar extending from the left edge of the path to the center of the path. It moves down the path in perspective.

#### k. Target symbol

- (1) Consists of a bright solid square that indicates the ground plan position of the target.
- (2) Information for positioning the target symbol is developed by the ballistics computer.

#### . Weapon symbol

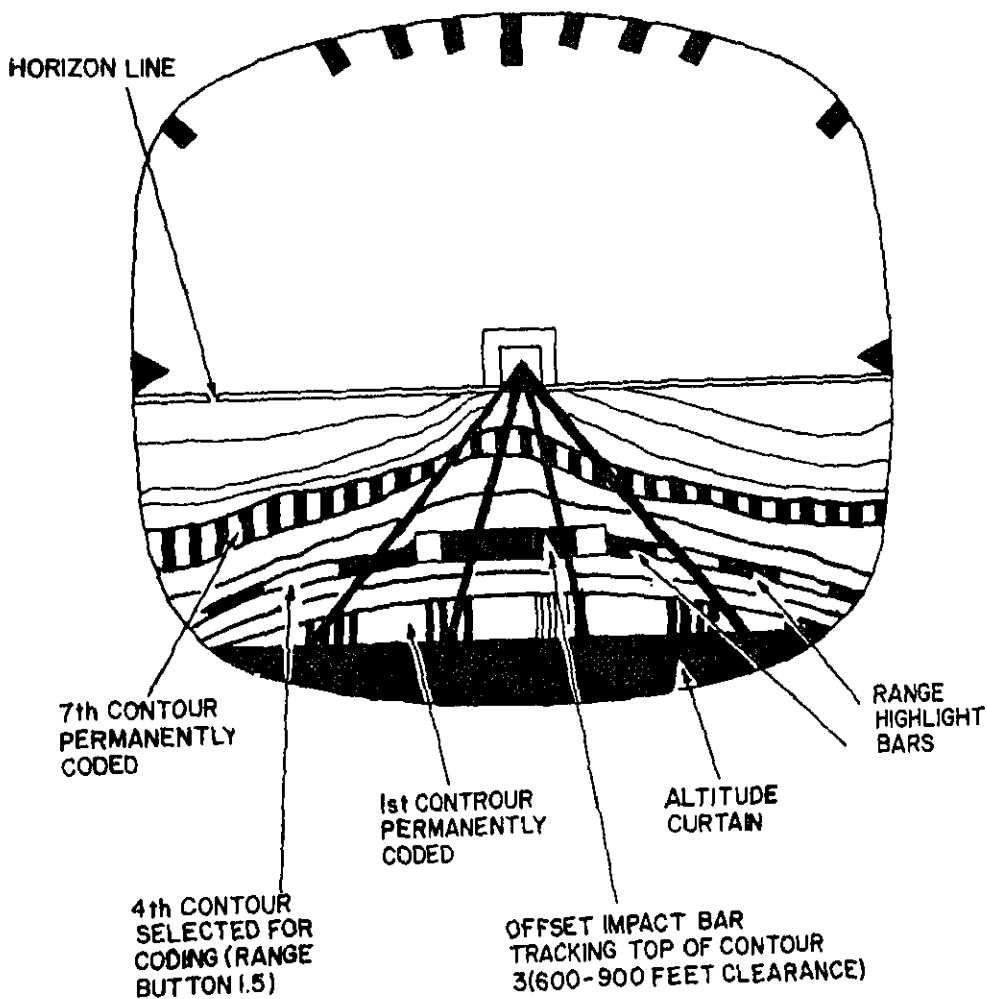
- (1) Consists of a bright hollow square that presents "G" and roll commands to the pilot.
- (2) Displacement of the symbol to the top of the display is the command to increase "G" and vice versa when displaced toward the bottom.
- (3) Displacement to the right is the command to bring the right wing down and to the left to bring the left wing down. Therefore, these are roll commands.
- (4) The ballistics computer provides the positioning signals for the weapon symbol.

#### . Release marker

- (1) Consists of a dark horizontal bar extending from the right side of the path and terminated by a short dark vertical bar in the center of the path.
- (2) The marker indicates the time to release the weapon when it reaches the bottom of the display.
- (3) The ballistics computer provides the positioning signal for the release marker.

- b. This is accomplished by generating a horizon line and 10 terrain profile lines, or range lines, on the display which represent 8.5 miles.
- c. The range lines are representative of the terrain ahead of the aircraft, and closely resemble that seen with the naked eye.
- d. The height relationship between the range lines and the horizon line is a function of aircraft altitude and the actual terrain.
- e. To create a real world dimensional effect, the range lines have varying brightness, that is, the nearest range line is the brightest while the farthest range line is the darkest.
- f. The symbols as seen on the display are as follows:
  - (1) Highlight bar - series of vertical bars which allow the pilot to detect heading changes relative to the aircraft.
    - (a) First and seventh range lines are highlighted.
    - (b) Either the 3rd, 4th, 5th, or 6th range line may also be selected for highlighting by the pilot utilizing positions 1, 1.5, 2, or 2.5 of the RANGE MILES switch of the PCF.
  - (2) Altitude curtain - is a blanking curtain which appears at the bottom of the TC display when the aircraft is approximately 600 feet above the terrain. If the aircraft descends to within approximately 20 feet, the curtain rises to the top of the display and then disappears at 20 feet.



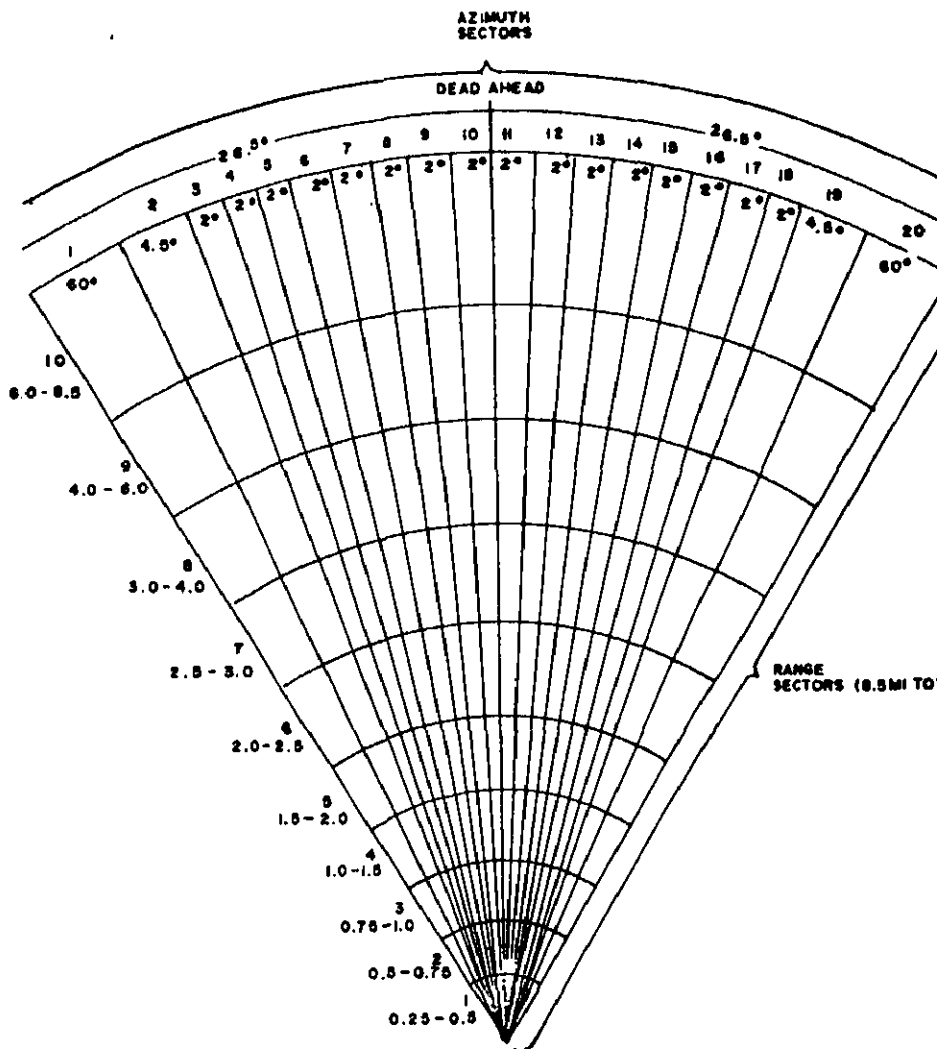


Terrain Clearance Display  
Figure 2

- (b) Pitch information from the INS also the marker in true perspective to display.
  - (c) The pilot manually positions the marker at some fixed range so as to maintain the aircraft so that the highest terrain is any closer than this fixed range. This is called terrain avoidance flying.
- (4) Calibration markers (confidence markers) are two markers normally positioned at the top side of the display.
- (a) The markers are located at  $-6^\circ$  reference and the other at zero degree (horizontal reference, approximately 3/4 inch from the first marker.
  - (b) The purpose of these markers is to provide to the pilot the degree of confidence he can place by providing an instantaneous continuous update indication of the terrain.
- 1) Elevation scaling, as indicated by the vertical spacing between the markers.
    - a) If the spacing decreases, the terrain display will appear to have a more gradual slope than the actual terrain.
    - b) If the spacing increases, the terrain display will appear to have a steeper slope than the actual terrain.
  - 2) Accuracy of the vertical range, as indicated by the position of the markers.
    - a) If the markers rise before the terrain reaches its normal position, the terrain will be displayed higher than it actually is.

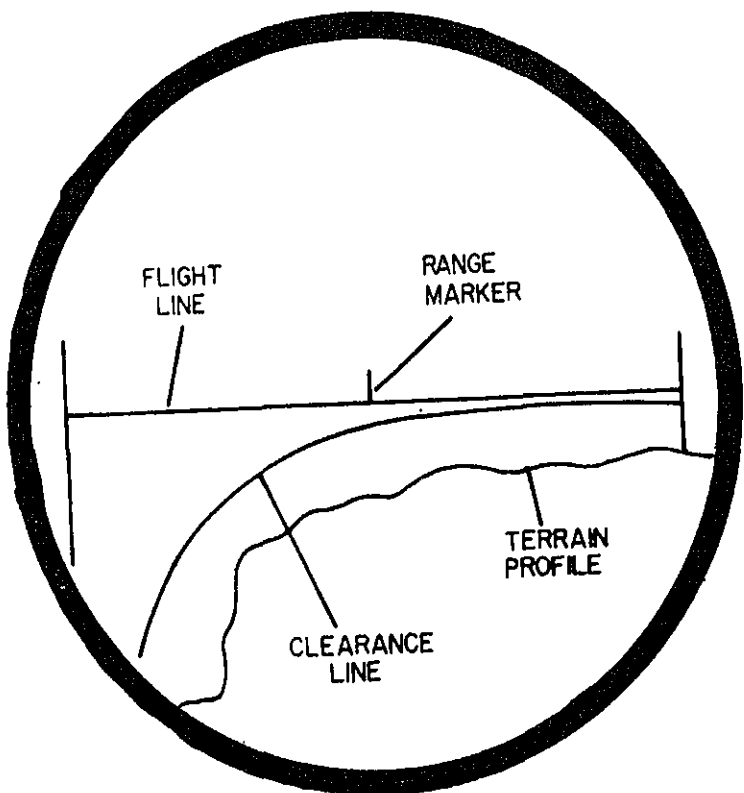
### 3. Basic TC video processing (Figure 3)

- a. The TC storage circuits are composed of 200 storage modules arranged so that 10 rows represent range and 20 columns represent azimuth (antenna position).
  - (1) Range consists of 8.5 NM of video in 10 range bins.
  - (2) Azimuth consists of  $53^\circ$  of video in 20 azimuth bins.
- b. By reading out the stored range/azimuth information at a rate determined by the ADI horizontal and vertical frequencies, a suitable TC picture will be displayed on the ADI.
- c. Note that the azimuth sectors are more narrow near the dead ahead azimuth bearing and are much wider near the azimuth extremes. This provides for the TC display to show more accurate terrain details ahead of the aircraft rather than at the edges where the terrain data is of less importance. This also holds true for the range distribution. The range sectors are smaller at the closer ranges than at the farther ranges where TC information is of less importance.



Basic TC Video  
FIGURE 3

2. E-scan - used to show the Pilot where he is in respect to the altitude and range of targets dead ahead. (Figure 4)



A TYPICAL E-SCAN DISPLAY  
FIGURE 4